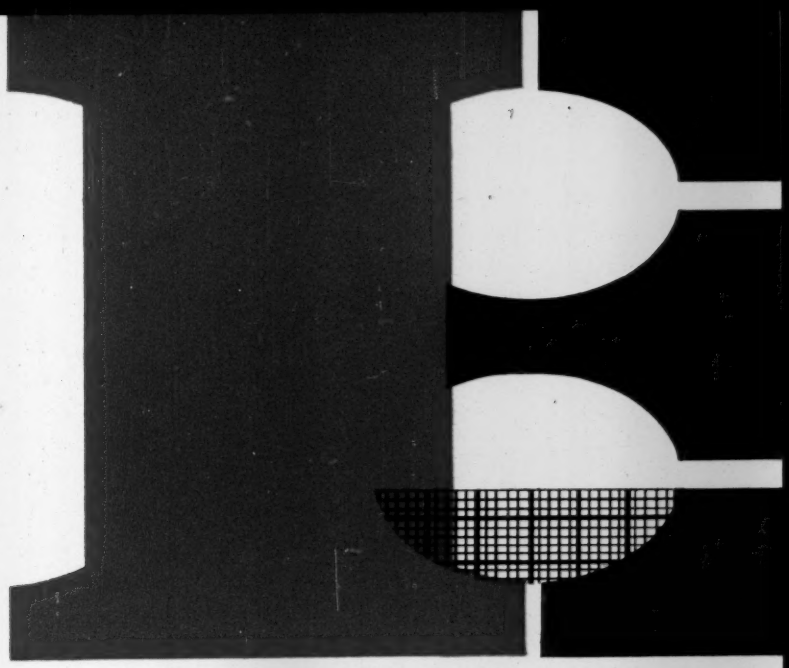

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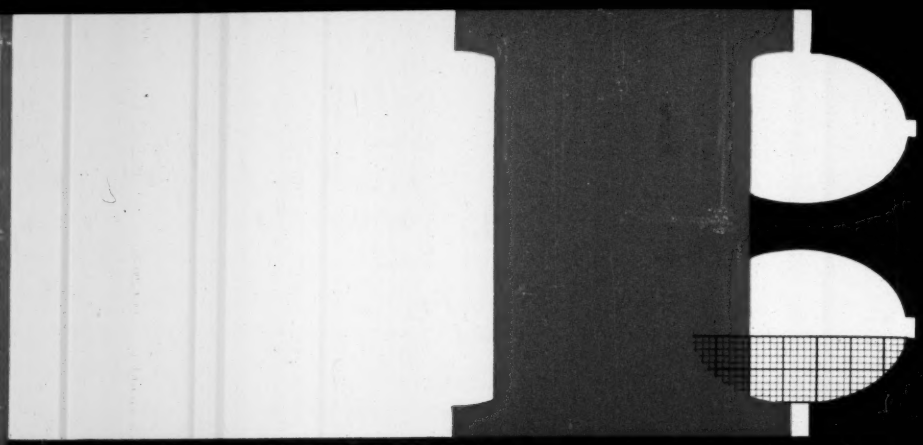

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A Linear Programming Application to Cupola Charging[1]

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General Motors Institute

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LEAST COST cupola charging can be accomplished with a relatively new analysis tool called linear programming. The purposes of this presentation are to:

1. Present some general information about linear programming.
2. Describe the cupola charge problem and the required linear programming formulation.
3. Describe how linear programming has been successfully used in a production foundry making cast and malleable iron.

No attempt will be made to describe any of the methods of linear programming. While the problems discussed are concerned with making cast or malleable iron, the general approach is equally valid for any blending type problem, i.e., any problem where a variety of items are mixed, blended, or melted to form an end product.

INTRODUCTION

Linear programming can best be defined as a group of mathematical techniques that can obtain the very best solution to problems which have many possible solutions. While a great many industrial problems fit this category of having many possible solutions, linear programming is not a magic panacea which will solve all problems. However, it can be used to solve a variety of industrial problems. For example, consider a four plant manufacturing system which manufactures an item and then ships it prepaid to a number of customers. Figure 1 illustrates the locations of the four plants, the customers and the sales regions allotted to each plant.

Historically, these four plants operated independently of one another. Linear programming was applied to the distribution of the product from these plants to the customers on the basis of the total four plant system, and resulted in a distribution pattern as shown in Figure 2.

This solution or pattern of shipping from the plants to the customers presents the lowest cost shipping program. If management deviates from this plan, the total costs would increase. For example, if management decided not to ship from the plant in Washington to the customer in Maine, but rather to ship to him from the plant in Pennsylvania, it would mean:

One or more changes in the shipments from the factory in Pennsylvania.

Several changes in the shipments from the factory in Indiana.

Several changes in the shipments from the factory in Kansas.

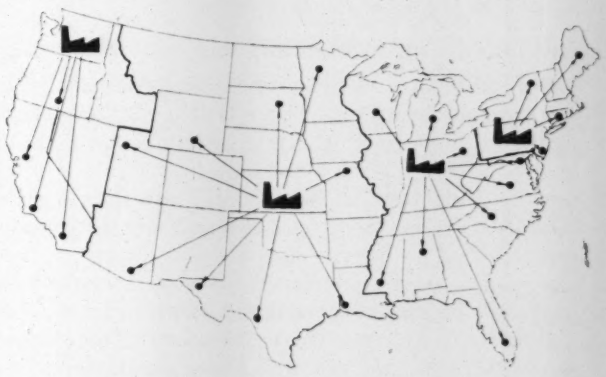


FIGURE 1. Present Method of Distribution.

[1] Based upon a presentation to the Saginaw Valley Chapter of AIIE, April 19, 1960.

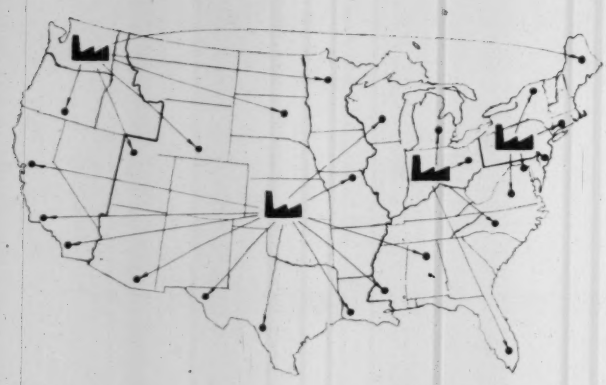


FIGURE 2. Least Cost Shipping Method via Linear Programming.

One or more changes in the shipments from the factory in Washington.

The net effect of all of the required shipping changes would result in increased total shipping costs.

This solution (Figure 2) also illustrates the situation where the very best solution is not necessarily the one that would be obtained by "cut and try" or intuitive methods. This is sometimes the case when solving a problem with linear programming.

The methods of linear programming present a step-by-step approach which, when followed, will arrive at the best solution. Not only is the best solution obtained, but information is provided which permits a rather quick analysis of the less-than-best or alternative answers. In the preceding problem, if management said that they did not wish to distribute from Washington to the customer in Maine, the linear programming solution immediately shows how much the total costs will increase and indicates all the prescribed changes that must be made to obtain the less-than-best solution.

In problems like this, standard analytical procedures fail because all facets of the problem are so highly interrelated. In these kinds of problems, it soon exceeds human capabilities to be able to consider all facets of the problem at the same time. Linear programming, however, is a tool of analysis which can and does consider every facet of the problem simultaneously.

THE CUPOLA CHARGE PROBLEM

The problem of charging or loading materials into a cupola is one which has many possible solutions. One of the basic problems in changing materials into a cupola, in making either ferrous or nonferrous alloys, is in determining how much of the available materials to charge in order to obtain the proper chemical and metallurgical properties at the lowest possible cost. Linear programming can be used to obtain the lowest cost charge which meets all the specifications of the melt.

In order to illustrate the problem and to show the results that were obtained with linear programming, two typical cupola charging problems will be discussed. One is typical of cupola charging in a high volume production foundry while the other is more typical of a smaller or custom foundry operation.

The linear programming analysis requires much the same information as presently used in cupola charging, namely:

1. A list of charge materials, their chemical analysis and cost per ton.
2. Chemical specifications of the charge (percent range for each element).
3. Any additional restrictions on the usage of the various charge materials.

The last item of information will include limitations on the use of certain materials either because of limited supplies or because of metallurgy requirements.

Before we consider a specific problem it may be advisable to examine the general linear programming approach to the cupola charging problem.

In order to use linear programming one must first describe his problem mathematically, in a set of equations or formulas.

To illustrate this, assume we have several materials that can be put into a cupola and melted to make grey or malleable iron. We will call them materials Number 1, Number 2, etc. Since we wish to determine how much of the materials to charge, we can let:

x_1 = percent of charge material Number 1 actually used.
x_2 = percent of charge material Number 2 actually used.
•
•
•
x_n = percent of charge material Number n actually used.

Then, what we want to do is calculate values for x_1, $x_2 \ldots x_n$ which will meet all the specifications of the charge at a minimum cost. Each specification takes the form of an equation or inequality. For example, suppose we consider the specifications for carbon obtained from the materials included in the charge. We can say:

$$ax_1 + bx_2 + cx_3 + \ldots nx_n \leq \text{maximum carbon (percent)}$$

where a, b, c, etc., are the percentages of carbon in each material 1, 2, 3, etc. This relationship says that the grand total of carbon which is contained in the various materials included in the charge cannot exceed the maximum carbon specification. A similar relationship must be expressed for the minimum carbon content namely:

$$ax_1 + bx_2 + cx_3 + \ldots nx_n \geq \text{minimum carbon (percent)}$$

These two relationships together make certain that the carbon specification will be satisfied.

In a similar manner, we can express the limitations for all the other elements like silicon, manganese, chrome, etc. In this manner, we can consider any number of chemical elements.

In developing a cupola charge, certain of the charge materials may be in limited supply and it may be undesirable to use more than a limited amount of other materials for various metallurgical reasons. These restrictions must also be included in the mathematical statement of the problem. For example, suppose that material Number 5 (x_5) is in limited supply and we only have enough to permit charging 30 percent. Therefore, we want to limit x_5 to a maximum value of .3 which can be expressed:

$$x_5 \leq .3.$$

In this way, we will permit no more than 30 percent of material Number 5 in the charge, if indeed it is profitable to use any of it at all. Similar restrictions can be placed on other materials in limited supply as well as those materials we wish to limit in the charge for metallurgical purposes.

A final equation is required in order to make certain that the solution gives percent of the various charge materials. The relationship:

$$x_1 + x_2 + x_3 + x_4 + \ldots x_n = 1.$$

Finally the formulation requires an objective. In this case our objective is minimum cost. Hence we include:

$$px_1 + qx_2 + rx_3 + \ldots = \text{minimum}$$

where:

p = the total cost per ton for material Number 1.
q = the total cost per ton for material Number 2.
•
•
•

Now the formulation or mathematical statement of the problem includes:

1. The system of relationships describing the problem.
2. The desired objective.

In this way, then, the mathematical statement of the problem describes or defines the problem and its limits. What linear programming does is to seek the best solution in terms of the objective within the limits described by the system of relationships.

A PROBLEM

In order to better illustrate this formulation consider the following problem:

A metallurgist has this problem:

Size of total charge	5000 lbs.
Amount of sprue and iron briquettes charged	3000 lbs.
Amount of "other material" to be charged	2000 lbs.

This 2000 lbs. of "other material" must contain:

At Least		*No More Than*	
60 lbs. carbon	3.0 %	70 lbs. carbon	3.5 %
54 lbs. silicon	2.7 %	60 lbs. silicon	3.0 %
27 lbs. manganese	1.35%	33 lbs. manganese	1.65%
6 lbs. chrome	.30%	9 lbs. chrome	.45%

The materials to be considered are:

	Cost/ Ton	*Carbon Percent*	*Silicon Percent*	*Manganese Percent*	*Chrome Percent*
x_1 Pig Iron	$ 60	4.00	2.25	.90	0
x_2 Silvery Pig	129	0	15.00	4.50	10.00
x_3 Ferro-Silicon Number 1	130	0	45.00	0	0
x_4 Ferro-Silicon Number 2	122	0	42.00	0	0
x_5 Alloy Number 1	200	0	18.00	60.00	0
x_6 Alloy Number 2	260	0	30.00	9.00	20.00
x_7 Alloy Number 3	238	0	25.00	33.00	8.00
x_8 Silicon-Carbide	160	15.00	30.00	0	0
x_9 Steel Number 1	42	.40	0	.90	0
x_{10} Steel Number 2	40	.10	0	.30	0
x_{11} Steel Number 3	39	.10	0	.30	0

Maximum usages (either due to limited supply or due to metallurgy requirements):

Silicon carbide, 20 pounds per charge
Steel Number 1, 200 pounds per charge
Steel Number 2, 200 pounds per charge
Steel Number 3, 200 pounds per charge

The problem is then to determine how much of which materials (x_1 through x_{11}) should make up the 2000 pounds at a minimum cost.

The problem must be stated mathematically. For instance, the carbon content of the input must be in a certain range. Each possible material contains a certain amount of carbon. Therefore, one mathematical relationship would be:

The sum of carbon in each material times the quantity of that material, must be above the minimum requirement of carbon in the final blend.

Thus, in this problem the first relationship becomes:

$$4x_1 + 15x_8 + .4x_9 + .1x_{10} + .1x_{11} \geq 3$$

(all numbers in percent)

where:

x_1 = percent (decimal) of pig iron included in the charge.
x_2 = percent (decimal) of silvery pig included in the charge.
•
•
•
x_{11} = percent (decimal) of Steel Number 3 included in the charge.

In order to assure that the carbon does not exceed the maximum specification we include:

$$4x_1 + 15x_8 + .4x_9 + .1x_{10} + .1x_{11} \leq 3.4.$$

Similar inequalities (relationships which have other than an equal sign) are established for all the chemical restrictions, i.e., silicon, manganese, and chrome.

The restrictions as to the use of these materials can be stated:

$$x_9 \leq .1$$

which means that x_9 (percent of Number 1 steel to be included in the charge) cannot exceed 10 percent.

The entire problem is then stated mathematically as given at top of the next page.

Minimize:

$$60x_1 + 129x_2 + 130x_3 + 122x_4 + 200x_5 + 260x_6 + 238x_7 + 160x_8 + 42x_9 + 40x_{10} + 39x_{11}$$

Subject to:

$$\text{(Carbon)} \quad 4x_1 + 15x_8 + .4x_9 + .1x_{10} + .1x_{11} \geq 3.00$$
$$4x_1 + 15x_8 + .4x_9 + .1x_{10} + .1x_{11} \leq 3.5$$

$$\text{(Silicon)} \quad 2.25x_1 + 15x_2 + 45x_3 + 42x_4 + 18x_5 + 30x_6 + 25x_7 + 30x_8 \geq 2.70$$
$$2.25x_1 + 15x_2 + 45x_3 + 42x_4 + 18x_5 + 30x_6 + 25x_7 + 30x_8 \leq 3.0$$

$$\text{(Manganese)} \quad .9x_1 + 4.5x_2 + 60x_5 + 9x_6 + 33x_7 + .9x_9 + .3x_{10} + .3x_{11} \geq 1.35$$
$$.9x_1 + 4.5x_2 + 60x_5 + 9x_6 + 33x_7 + .9x_9 + .3x_{10} + .3x_{11} \leq 1.65$$

$$\text{(Chrome)} \quad 10x_2 + 20x_6 + 8x_7 \geq .30$$
$$10x_2 + 20x_6 + 8x_7 \leq .45$$

$$\text{(Total Melt)} \quad x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 + x_{10} + x_{11} = 1.0$$

Maximum usages:

$$x_8 \leq .01$$
$$x_9 \leq .10$$
$$x_{10} \leq .10$$
$$x_{11} \leq .10$$

With this mathematical statement, the problem is ready for linear programming. The objective or cost equation indicates that we desire the answer with the lowest possible cost and one which is within the limitations described in the set of relationships. This formulation or mathematical statement of the problem can be solved with the simplex method of linear programming. While we will not consider the details of the simplex method here, let's take a look at the lowest cost solution which the simplex method provides.

The least cost solution is as follows.[2]

Variable	*Value*	*Description*	*lbs./2000 lbs.*
x_{11}	.10	10% Steel Number 3 in the charge	200.00
x_4	.011	1.1% FeSi Number 2 in the charge	22.0
x_5	.00711	.711% Alloy Number 1 in the charge	14.22
x_2	.03	3% Silvery Pig in the charge	60.0
x_1	.73713	73.713% Pig Iron in the charge	1474.26
x_{10}	.01472	1.472% Steel Number 2 in the charge	29.44
x_9	.10	10% Steel Number in the charge	200.00
			1999.92 lbs.

Total Cost Per Ton $59.56.

This charge results in minimum amounts of the four elements carbon, silicon, manganese, and chrome. As mentioned earlier linear programming not only provides the best solution (lowest cost in the case) but it provides information about less than best or alternative solutions. The linear programming solution for this problem also gives the following information for those materials not in charge:

Material	*Marginal Cost*
(x_3) FeSi Number 1	2.07
(x_6) Alloy Number 2	41.01
(x_7) Alloy Number 3	39.85
(x_8) SiC	6.71

These marginal costs indicate the amount of reduction in price per ton that must occur before these materials can be included in the charge, i.e., Alloy Number 2 will be profitable to use only if its price per ton is reduced by $41.01 per ton—from $260.00 to $218.99 per ton. These marginal costs give management an indication of the penalties incurred for deviating from the best solution. These can also be used very profitably by the purchasing agent in his dealings with suppliers.

Additional marginal costs are provided which can be used to study the effect of changing the chemical requirements of the charge. These marginal costs for this problem are:

Element	*Marginal Cost*
Carbon	3.67
Silicon	1.98
Manganese	2.09
Chrome	5.09

which can be interpreted:

Carbon—If we raise the minimum carbon content in the charge by 1 percent this will increase the charge cost by $3.67 per ton. An increase of .1 percent will increase the charge costs by $.37 per ton. Also a decrease of 1 percent in the minimum carbon content will decrease the charge cost by $3.67 per ton.

A similar interpretation can be developed for each of the other elements.

The analysis of the marginal cost provided by the linear programming solution are often of more value than the specific least cost charge in that they give management a quantitative measure of penalties and hence a measure of operating flexibility.

[2] It should be noted that the formulation of this problem can be reduced in size. The same solution can be obtained if we omit the upper limit relationships on carbon, silicon, manganese and chrome. In solving more than 30 similar cupola charging problems for both cast and malleable iron it was found that the optimum (lowest cost) solution always resulted in charges exactly at the lower limit specification. With this experience it seems reasonable to formulate a cupola charge problem without the upper limits and include these only if the solution demands them. This is a practical approach even when high speed computing equipment is readily available.

THE PROGRAM IN A PRODUCTION FOUNDRY

Aside from the mathematics involved in applying linear programming, many problems can be encountered in putting this into effect in a production foundry.

In the summer of 1958 a study was initiated in a production foundry to determine the feasibility of applying linear programming to the cupola charge problem. During the early stages of the study it became apparent that the linear programming calculations (for the simplex method) presented an enormous chore. Therefore, a high speed computer was used for these calculations. This is not to say that these calculations cannot be accomplished by hand. However a high speed computer can solve a problem like the one described previously in several minutes whereas it would require three to six hours to accomplish the same thing by hand.

In addition to the bulk of calculations other problems were encountered. Initially, the solutions which were obtained were not valid. Some of this was due to incorrect data, errors in the data, and omissions in the statement of the problem. In one case, a solution specified a relatively high usage of a certain scrap steel. This was not acceptable because the supply of this scrap steel was sufficient for only a few days of operation at the rate of usage indicated by the solution. Since a solution was desired which could be used throughout one production month, it was necessary to restrict the permissible amount of this scrap steel in the charge so that the available quantity would last for one month's operation.

In another case, a solution indicated sizable savings over the present charge. However this solution was not acceptable to the metallurgist because, while the low limit on one element was .65 percent, the metallurgist felt that the nature of the cupola operation required a charge with closer to .70 percent of this element. Since the linear programming solution usually develops a charge with exactly minimum amounts of the various elements, the data had to be revised so that in effect the minimum specification on this element was .70 percent. This type of thing may happen with the more expensive elements in a charge.

In still another case, the solution was invalid because the data ignored the fact that one charge material was not fully recovered in the melt. Neglecting losses in melting usually leads to an unusable solution.

Errors appeared in one solution because several charge materials were grouped together and handled collectively as if they were one material. This resulted in erroneous answers because the costs of each material as well as the chemical analysis was slightly different. It was just enough different that when the materials were handled individually, the linear programming solution used all of one and none of the other materials. Here it became apparent that in any solution, all possible materials should be considered individually as separate materials even though costs and analyses are nearly the same. These early solutions, even though invalid, were useful in demonstrating the sensitivity of the linear programming analysis and the need for a complete statement of the problem.

It is important to realize that anyone beginning an analysis of cupola charging via linear programming should not expect perfect results the first time. Indeed, it is only after several invalid solutions that one fully appreciates the ultimate value of the analysis.

In the early stages of the study, relatively few possible charge materials were considered. Many materials were omitted because at one time in the past they were evaluated and were not profitable to use at that time. However, as cupola charge specifications change, and with the fluctuations in material costs from time to time, it was found that several of these materials now could be profitably included in the charge. Hence, subsequent problems have considered all possible charge materials. Here, it is necessary for us to consider an important factor in understanding the application of linear programming. Intuitive or inspection method may often yield the best solution when relatively few charge materials are considered. These methods, however, become increasingly less effective as the number of materials to be considered increases. The larger the number of materials, the more difficult it becomes to analyze the complex interaction of material analyses and costs by cut and try methods. Linear programming can determine the lowest cost charge regardless of the number of charge materials to be considered.

Some of the results of the early parts of the study were useful in indicating the effects of a change in chemical specifications on charge costs. It was found that for certain elements a very slight change (in hundredths of percent) would show a marked increase or decrease in the cost and make-up of the least cost charge.

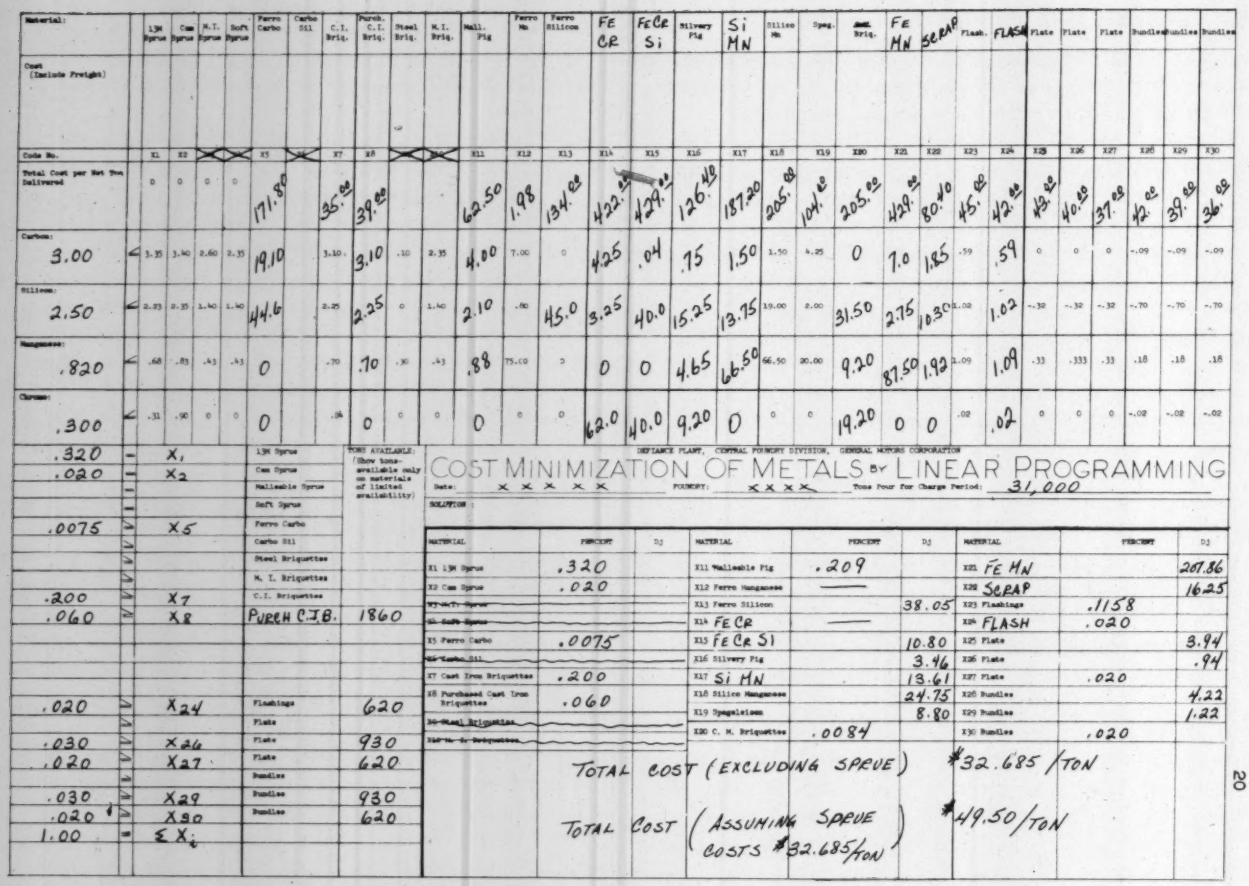
The initial study finally indicated that linear programming was feasible and savings from $.15 to $.45 per ton might be realized. Therefore, in the spring of 1959, it was decided to use linear programming for cupola charging. It was decided to solve the problem twice per month in order to:

Determine the lowest cost charge considering all the materials available for purchase.

Determine the lowest cost charge in terms of the materials on hand.

The first solution was developed from data prepared by the purchasing agent and the metallurgist. The purchasing agent indicated what materials were available, their delivered cost per ton, and available quantity. The metallurgist specified the desired minimum chemical content of the charge, the approximate chemical analyses of the charge materials, and any limitations on the use of certain charge materials. This solution was then used as a guide by the purchasing agent in buying materials.

Later in the month the second solution was obtained. Here the actual costs, quantities, and chemical analyses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SOLUTION
TOTAL COST (EXCLUDING SPRUE) #32.685/TON
TOTAL COST (ASSUMING SPRUE COSTS #32.685/TON) #49.50/TON

FIGURE 3. The Data and Least Cost Solution.

of the materials on hand were used to determine the least cost charge. This was used as a guide by the metallurgist in charging the cupola.

In putting the linear programming on a production basis a form was developed to facilitate data collection. Figure 3 illustrates the form that is used for the linear programming analysis. Space is provided for the data prepared by the purchasing agent, metallurgist, and the mathematician. The analysis of certain materials remains relatively constant, so its analysis is printed on the form. Each column in the upper half of the form represents a charge material or space for one. The rows represent (from top to bottom):

1. The identification or name of the material.
2. Cost (including freight)—this may be cost per ton or cost per car load.
3. Code number—this identifies the material for the mathematician.
4. Total cost per net ton delivered—this is the numerical quantity used in the linear programming analysis.

5-8. Four rows for the chemical content for carbon, silicon, manganese, and chrome in the various materials and the charge.

You will note that plate (X25, X26, X27) and bundles (X28, X29, X30) seem to have negative amounts of the various elements. During the course of the study it was found that the use of plate and bundles in a charge tends to reduce the recovery of certain of the elements in the final melt. The negative numbers reflect the influence of these materials on the recovery of the chemical elements. These corrections or modifications were made after several months of operating experience with linear programming. It is interesting to note, here, that these corrections came to light primarily due to the fact that the charges developed by linear programming always result in exactly the minimum chemical content. Without these correction factors some charges resulted in melt which was below the minimum specification on certain elements.

This form is started by the purchasing agent who fills in data concerning the cost and availability of materials for charging the cupola. The form is then sent to the metallurgist, who indicates the minimum chemical specifications, chemical analyses of the available charge materials, any limitations on the use of charge materials, and the total tonnage projected for the period.

The form is then sent to the mathematician who checks

the data to see that they are complete and converts the availability of the materials in limited supply from tons to percent. The data are then ready for linear programming.

The solution obtained with a high speed computer is recorded by the mathematician on the data form. The solution is in two parts. First, the percent of the various materials in the charge is noted in the Percent column. The D_j column is used to record the marginal costs of the materials not used in the charge. As mentioned earlier, linear programming not only determines the best solution but it also provides information about less-than-best solutions. The numbers (D_j) for those materials not used in the charge indicate the reduction in price per ton required before these materials could be profitably ed in the charge. This is commonly called a marginal t. This, then, provides the purchasing agent with a gaining point when talking with the scrap dealers. rices can be obtained which are lower than the original quoted prices, by the amount of the marginal cost, then the purchasing agent purchases the lower priced material. When this happens it becomes necessary to resolve the problem after the materials are delivered in order to determine the cupola charge.

The second solution per month, if necessary, is handled by the metallurgist and the mathematician since they are considering only those materials available in inventory.

After four months of operation, a cost and savings analysis was made. To be certain, it is difficult to exactly determine what might have been done without linear programming. However, the analysis indicated savings from \$.10 to \$1.40 per ton with the average at \$.51 per ton for the entire four month period. The cost of linear programming solutions must be deducted from the foregoing. However, since the total cost per solution is only about \$25.00, this is quite negligible. Each problem would require a day or more to solve by hand, but requires less than one minute on an IBM 704 computer.

This application of linear programming has not only reduced cupola charge costs, but it has opened the door to other operating cost reductions. In fact, the other cost reductions in materials and operating procedures have been several times the savings obtained by linear programming.

These savings have been realized in making malleable iron where we are concerned with only a few chemical elements. In making aluminum alloys, usually a greater number of elements with much closer specifications must be considered. Here linear programming is even more valuable for determining the least cost charge which satisfies all the specifications.

SUMMARY

In the past decade, technological progress has been made in mathematics as well as in other fields of science. The results obtained by using linear programming in cupola charging reflect the advantages of this new mathematical technique. Essentially, linear programming does the clerical task that used to require a sizeable portion of the metallurgist's time and energy. Linear programming has become an important new tool which depends very heavily upon the close cooperation of metallurgist, purchasing agent, and mathematician. This is a new addition to the many mathematical and statistical tools available for analyzing foundry operating problems.

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Engineers and Computists*

by **WILLIAM A. SMITH, JR.**

Director, Computing Laboratory, Bethlehem, Pennsylvania

ALTHOUGH digital computers have been available less than ten years, their introduction has made a resounding impact on both data processing and engineering or scientific work. Successful applications, from cost and design standpoints, are all about you. Literature can be found in every professional field extolling the virtues of computer applications and describing "how" and "why" such applications were made. For instance, the United States Steel Company Magazine of January, 1958 reported that data processing equipment saved the Corporation an estimated 100,000 engineering man-hours during 1957 alone and looked hopefully to increased savings in the future.

Most of the efforts of computer-oriented people—referred to here as computists—have been to convince people to try the new gadget and to explore the unbounded horizons of their work. The emphasis should have been and must now be on indoctrinating engineers and scientists to use computers intelligently and economically. If you are an imaginative engineer, the need for computational assistance will arise if it has not already done so. The challenge is to develop the most meaningful results economically feasible.

The use of computers makes sense to people who have accomplished worthwhile calculations. To those who have experienced poor results or have not had an opportunity to apply computers, such a device often seems to be just a distraction to the achievement of their primary objectives. If your application has failed, the limitations were probably human rather than machine. Should you feel that a computer has not been available to you perhaps you have not fully explored the possibilities. Most large companies have facilities available to engineers, or digital computers can be purchased ranging in price from ten thousand dollars to ten million dollars. A service-rendering firm has recently announced rented computer time costing—in the vernacular of tradespeople—as little as $10 per month.

Oh, yes, there has been another deterrent to computer solution of problems—lack of sympathetic supervision. It is rather startling that if an engineer with five years' experience had done nothing but calculate manually in those years, a computer could turn out the same volume of calculation in about fifteen minutes. More and more engineering graduates are going to start their first jobs with computer experience and they will be expecting guidance in making new applications to conserve time and money. Supervisors owe their engineers the opportunity to enhance computing skills.

In light of the rapid increase of acceptance of computers, including more intensive education in colleges, the author assumes that the utility of such equipment is generally recognized and this discussion will focus attention on the mutual interest of the engineer and the computist.

APPLICATIONS

Many early applications of the general purpose digital computer were not too successful, even though such equipment was advertised to solve any mathematical problem to required accuracy. The glowing claims for cost reduction and effortless application proved difficult to achieve and, quite often, they were improper objectives. In this day, a fair statement of advantages for applying computers to engineering calculations are:

1. Information can be obtained faster, hence earlier.
2. More *useful* information can be analyzed or assembled.
3. Mathematical models can be more accurate.
4. Alternative solutions can be more readily achieved.
5. Standardization of approach can be achieved.
6. Reliability of results is greater than for manual methods.
7. Better methods are available to inexperienced personnel.
8. Drudgery of engineering work can be lightened.

This is an impressive list, but none of the items can be realized unless exacting problem preparation is made. From several sources, accusations have been made that computers give engineers an "excuse to quit thinking." To the contrary, many engineers have found themselves unable to solve, or to even describe, problems confronting them when a computer provided the means of solution. The well-conceived program can be a useful device for indoctrinating personnel to new or preferred methods of solution. Also, the above comment assumes that the engineer is always doing creative, analytical work and that each completed program offers a solution to a problem for all time. Experience has shown neither to be true. In contrast, some engineering supervisors state that utilization of a computer on worthwhile problems is a mark of the valuable engineer. Such people are skeptical about the engineering contribution of those whose imagination and analytical ability have not created a need for computational assistance.

While these points of view may be extreme, there is no doubt that some practicing engineers and their supervisors have a lack of scientific approach and too great a reliance upon the "cookbook." For example, consider

* Based upon a presentation to the Eighth Annual Engineering Management Conference, September 15-16, 1960.

two senior engineers preparing a design application for the computer. Several times they came to impasse when they differed on the "way we do it at our company." In each instance, the supervisor was surprised to find that actual design practices differed from his recollection or instruction. As is normal for such a problem, several points were also reached where no explanation or logical rule for action could be described. Recesses were then in order to determine how these dilemmas were overcome in daily practice by the technical personnel. In this example, the method of calculation was standardized, logical steps replaced widely varied "educated guesses", and cost estimates improved before getting to the computer.

To be useful, programs should allow things to be done that are not now feasible from a cost or time point of view. Just transferring hand methods to a computer will generally result in little advantage except education of the personnel. Routine transfer of existing methods doomed to failure many early applications. All the limitations of the old method are preserved when more exacting methods could usually be employed. If you must be satisfied with manual methods, which are usually characterized by excessive shortcuts, at least explore alternatives at great length. Just to recognize areas where you need analytical or computational assistance, demands that you know the limitations of various methods of solution. For a civil engineer designing a bridge, the steps of sophistication might be:

1. Present design methods on the computer to familiarize personnel with computer.
2. Improved methods with alternative designs and sizes examined to realize problem-solving advantages.
3. Transfer of decision-making to the computer, e.g., by giving it the slopes of the steam banks and letting the program choose the best method for crossing (bridge, tunnel, etc.) and the optimum design.

If the last step seems far away, it is only because we as engineers have difficulty in visualizing how one might instruct a machine, or person, to make these decisions. The computer patiently awaits our creative talents.

The foregoing example is one of design and development, which is an important type of engineering calculation. Another use is data reduction and statistical analysis. While curve-fitting may have become a pleasure with the computer, we—engineers and computists—still are uncertain of our ground when using many advanced statistical concepts. Also based on stochastic principles, simulation has fast become an important tool that is nearly impossible to achieve in desired or meaningful magnitude without a computer. Engineers must learn a great deal more about the best methods of simulating probabilistic model situations. Another area of interest, process control, demands knowledge of both digital and analog computer devices. Their successful marriage in systems may create invaluable tools for the engineer. Unhappily, the individual usually thinks of problems in regard to only one area of application at a time. For example, a young engineer was contemplating calculation of some reasonably well-described functions detailing a process. Upon being asked about input data for these formulas, he explained that he would derive the numbers after several days of manipulating matrices on the desk calculator. He did not think that the data output format was too important because multiple correlation of the results was necessary on the desk calculator. After lengthy discussion and assurance that matrix operations and statistics were bread and butter for the computer, the individual was finally convinced that several weeks of his time could be saved by starting the computer solution with the matrix operations and completing with the statistical analysis.

PROGRAMMING

If an entire problem cannot be solved by using programs readily available in a library, (e.g., curve-fitting, statistical, or matrix operations) the desired calculations must be programmed. Before approaching the computer, the problem at hand must be stated in detail and the analytical tools carefully chosen. These first steps are required for good engineering practice anyway. Remember that the computer is quite unimaginative and it will not fill gaps in your understanding of the problem. It may seem strange to dwell on this point, but at this step the engineer should muster all his skill to describe the method of solution exactly as it should be. Should this sound easy, you probably have not been in the throes of detailing the exact sequences of a problem solution for a while. In one case, negotiations for a proposed computer application were conducted intermittently for three years between well-trained and experienced individuals. Twice, final decisions were made on the equations and procedures to be solved, but neither got to the computation stage. After those three years and the efforts of several individuals, the problem remained undefined. The parties were able to agree on only one fact—the nature of the problem was fundamentally statistical.

In many respects, programming has been simplified and will be made easier in the future by problem-oriented languages. Tool engineers, process engineers, structural engineers, etc. will soon have descriptive languages using their own vernacular to describe the logical structure of problems to be solved. This makes it easier for the practitioner to use the computer, but the value of such a routine is determined by the combined computing and engineering skills of those devising the language system. Engineers must develop such systems to satisfy the needs of sound engineering practice. The computist must insure that this same system can be applied to a wide range of computers with the maximum efficiency for each. Progress has already been made for algebraic language systems. In any event, remember that, in spite of these aids, the responsibility for correctly solving a problem rests with the engineer. The computists can advise on numeri-

cal methods and create more efficient computing techniques, but rarely does he fully understand the engineer's problem-solving need.

The detailed layout of instructions in computer language, or coding, can be accomplished by the computer itself when the engineer expresses his problem in an acceptable symbolic or problem-oriented language. Although this increases computing time, it allows the engineer to concentrate on the problem rather than the computer. The engineer may have to deal with machine language for unusual problems, when running time is critical, or for making alterations in existing programs. Let me assure you that such endeavor may consume large amounts of time and that the reward should be future savings in time and money. If you turn the details of coding over to the computist, the time and expense of preparation have not been eliminated; they have simply been delivered from under your control.

Once the program is fully described in computer language, whether written manually or by the computer, the engineer must check for errors in his analytical techniques or in preparation of the computer program. This is done by trying all aspects of the program with data for which answers are known. The responsibility for determining the accuracy of an application rests with the engineer. The computist must assist him in finding the source of variance when one exists. It is rare that a program will work correctly at first try. Time, patience and explicit statements in early stages will eliminate the major portions of time-consuming and exasperating effort required during checkout, or debugging. If you want sound answers later, expect this phase to be exhaustive, and have infinite patience. In essence, programming is no different from any other design effort and it should be treated with the same accord.

To this point, the discussion has centered on telling the computer how the problem should be solved. The payoff can be achieved only after these steps have been satisfactorily completed. Each hour of careful preparation will enhance the efficiency of operation when actually running the computer for problem-solving. Just as for any design effort, the program is an investment that will not realize a return until it or the original thinking producing it is put in use. Remember that some designs are never used, many are used with alteration, and a few are utilized repeatedly for great time and economic advantage.

Engineers and computists alike should strive for the last-mentioned situation, but engineering applications differ and new ideas develop. In order to preserve the investment in a program, there must be facility for alterations. This can be achieved only through careful documentation of the successfully running program. Each routine should be described in writing so explicity that persons who are not familiar with the program can accept correct input data, use the routine, and return meaningful results. The computist is often satisfied when results come from the computer. Reappraising the program and incorporating all those little last-minute changes are often not important, in his mind, when the program works. But, ask the computist about these little changes six months later or suggest some alterations to the program that is not well-documented. Watch the pain that appears in his expression as he contemplates the effort involved in reconstructing past achievements. Did you ever wonder why it sometimes took as long to write the description of a program as it did to write the program? Remember the potential saving when you hand that description to a new engineer or another division of the company without any time required for great explanation—mentioning only that the author is no longer with the company. If you think the time to develop a program has been excessive, remember that you can prove your point by not demanding accurate documentation of the results. A good description can preserve the earlier investment.

CONCLUSION

Whether computers are not sufficiently advanced to solve your problems or you are not sufficiently enlightened to gainfully use a computer, they have made a resounding impact upon engineering and they will gain in importance. They are still relatively new, and time remains for each individual to indoctrinate himself in their useful application. Most of us have many years of exposure to computing left before retirement. The question is when do we start, not should we learn.

From the growing pains of machine computation emerges the demand for engineers who can better adapt computers to the needs of others in their profession. The maximum advantage of computers will not be realized, however, until engineers initiate more creative, analytical work and then are willing to invest time and effort required to carry their ideas to fruition. Computists must constantly strive to enhance the engineer's efficiency by encouraging better analysis and by devising improved methods and equipment.

Computer applications may be fast and they should save the engineer from repetitive, personal calculation, but sound analysis is essential for meaningful results. The preparation for problem-solving may be painstaking—often exasperating—and the result will be no cure-all. If engineers and computists face the challenge with cooperative determination, however, the most successful computer applications of this decade will refer to areas and methods not yet envisioned today.

Probability Based Tolerances in Forecasting and Planning*

by **CHARLES D. FLAGLE**

Director of Operations Research, Johns Hopkins Hospital

THE ADMINISTRATIVE function of planning contains as its major decisions the selection of a course of action, the division of the resulting tasks among the resources of the organization, and the conception of the plan as a program in time. These three decisions are essentially interdependent, since the alternatives from which a set of actions can be chosen are limited by the availability of physical and human resources and time.

In the first stages of planning, the estimates of time and resources need be sufficient only to test the feasibility of actions considered. However, once the scope of action is decided upon and the organizational personnel and facilities are assigned, it remains to fit the plan into a timetable. It is this last activity, characterized as forecasting or scheduling, which is to be discussed here. The term forecasting connotes prediction, or in our case, the estimation of time requirements for operations. The term scheduling connotes the allocation of available time and facilities, guided by forecasts.

The technique to be described here requires recognition of the distinction between forecasting and scheduling, for it is by alternate applications of each activity that a plan is converted to a program. The technique requires also that the scheduling phase of planning be perceived as a continuous—or at least intermittent—activity in which actual progress is compared with scheduled progress at times when action can be taken to remedy discrepancies between the two.

HISTORICAL BACKGROUND

Such a concept of scheduling is epitomized in the well known Gantt Chart, widely used in industry for many years. It is the purpose of this presentation to introduce a modification to this established technique which shows the measure of uncertainty in schedules, and thereby extend use of the Gantt Chart to programs in which the inherent uncertainties of time estimation are large. A brief examination of the history of the Gantt Chart and the areas and forms in which it is currently used is in order as background for subsequent discussion.

It is of more than passing interest to note that Henry Laurence Gantt conceived the system of scheduling which bears his name, while concerned with a military problem, the coordination large scale procurement of material and training of men. It was in 1917 that Gantt, already renowned for his contributions to scientific management in industry, volunteered his full effort to the mobilization for World War I. Assigned to the Army Department of Ordnance and charged with the task of coordinating munitions procurement, he quickly devised a graphical system for presenting comprehensively the scheduled requirements for the vast complex of munitions in such a way that actual procurement could be checked against the schedule. The key to the conception of this graph or chart was the recognition of time as the inexorable variable common to every item or operation in the schedule. The key to the dramatic success of the technique lay in its unmistakable revelation of trouble spots to those with authority to institute corrective action.

Gantt applied his scheduling system to other phases of the war effort, and within a short time, its use spread to industry. While conceived as a system of coordination at the highest strategic planning level, the Gantt Chart, because of its simplicity and the universality of its underlying assumptions, permeated a variety of organizational activities at all levels where scheduling was required.

GENERAL PROPERTIES OF THE GANTT CHART

The procedure for expressing a program in the form of a Gantt Chart requires first the division of the plan into a comprehensive set of operations. These are interdependent to the extent that each must be complete before the plan as a whole is complete. Further, the beginning of some operations may be signaled by decisions which can be made only after certain progress in other operations. However, once begun, it is assumed that each operation

* In this article, written some five years ago and presented first in the Johns Hopkins Informal Seminars in Operations Research, later with modification as a master's essay in Industrial Engineering, Dr. Charles Flagle has been quite perceptive in his recognition of the need for and utility of including variability in the scheduling process. The notions expressed in this paper have proved especially useful in connection with managing large-scale research and development programs. For example, similar concepts have been developed and successfully utilized in the Navy's computerized PERT system for the Polaris program. Flagle's paper, an untried concept when written, is now required reading for Industrial Engineers and managers.—*D. G. Malcolm*

may proceed relatively independently of progress in others.

The second step requires the division of each operation into a sequence of phases, characterized by the necessity for completion of any one phase before beginning of the next. For the purposes of this article, some common terminology has been given special meaning in order to picture a plan as a set of operations being carried out in parallel, each consisting of a set of phases being carried out in series, or sequentially.

The third step is the estimation of time required (or allocation of time available) for performance of each in the sequences of operational phases. The chart can then be prepared by listing operations and plotting along an axis of calendar time a series of brackets which enclose the estimated time intervals for each phase. At this stage we have created the first estimate of the plan fitted into a logical time-table. In order to do this, it has been necessary to visualize for each phase some quantitative measure of performance as a function of time. What appears on the Gantt Chart is effectively a set of transformations of these quantitative measures of performance to their common variable, time. Such transformations, which may be plotted for each operation separately on "backup charts," imply that any stage of phase progress can be represented as point in time on the Gantt Chart. Thus, we have a mechanism for periodic review in which actual performance can be compared visually with scheduled progress. Upon a chosen review date, a set of progress bars can be drawn in the time brackets, extending from the starting date to that date on which the actual progress would have been achieved under the schedule. The progress bar will extend beyond the review date for an operation ahead of schedule and will fall short of the review date for one behind schedule. Areas of the program are thereby revealed in which some action is necessary to restore balance, or rescheduling is required to produce a more realistic conception of the program time-table.

Figure 1 is a reproduction of part of a Gantt Chart prepared by Dean R. H. Roy for scheduling facilities expansion in a printing plant. Dates of review are marked by arrows on the time scale, which indicate that progress bars reflect the situation at mid-September, 1947. The chart tells that composing room equipment has been received and installed but that hiring and training of personnel is generally lagging.

It takes little experience or imagination to perceive that under the progress bar system of review, the time estimates become goals, and that the ego involvement of personnel in the various operations is extended to the attainment of these goals. This is characteristic of Gantt's techniques, for he correctly recognized the potentially large increments of performance to be realized by creating ego involvement in the task. It must be admitted, however, that such involvement is not an unmixed blessing, a fact which becomes apparent at the stage of planning in which performance time requirements must be estimated.

We need only refer to Gantt's biography for evidence of the difficulty of obtaining objective and truthful estimates for scheduling and review (1). A tendency toward the extremes of unrealistically optimistic or overly cautious estimates is understandable, since either of them reflects favorably—temporarily at least—upon the estimater, the former at the time of drawing up the

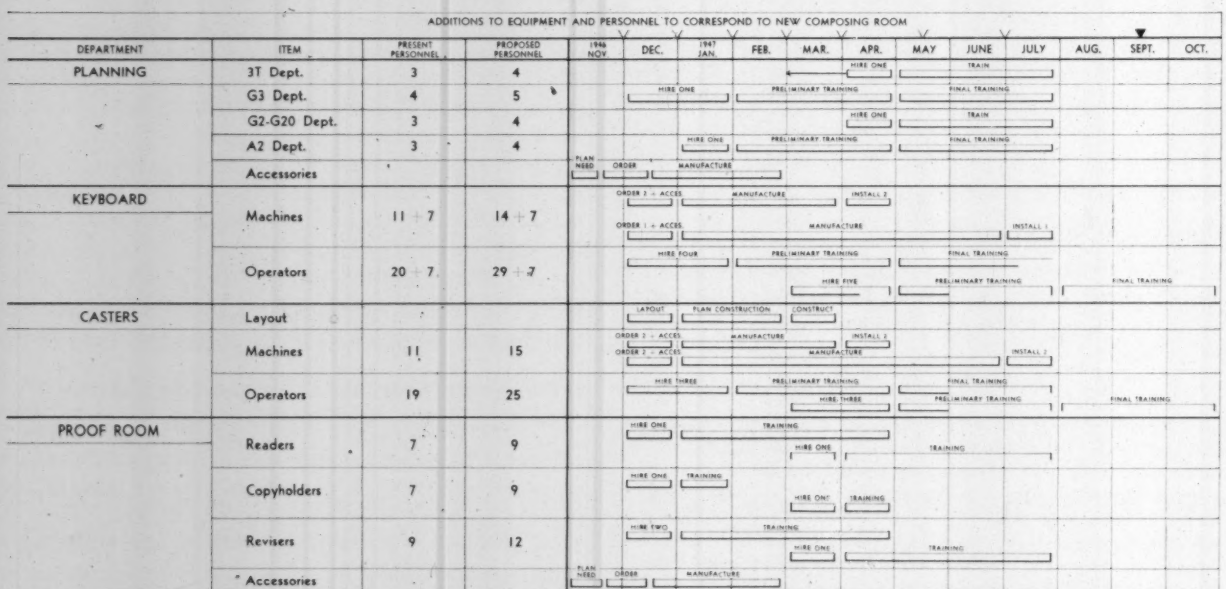

FIGURE 1. A Gantt Chart Used in Industrial Engineering.

schedule and the latter at the time of review. The prevalence of extreme estimates and efforts to avoid estimation on the grounds of uncertainties have called forth some "legislation" in W. J. King's "The Unwritten Laws of Engineering." King recommends use in planning of estimates midway between the estimated extremes (2).

Salveson gives an example of the scatter of actual performance about scheduled performance in aircraft production (3). In a sample of some 700 parts, 330 were behind schedule, and 240 of them lagged sufficiently to exhaust their inventory. Meanwhile, 361 parts were ahead of schedule.

The essence of this article is to propose acceptance of uncertainties in time requirements as an unavoidable property of many operations which must be scheduled, and further, to propose that quantitative estimates of these uncertainties be incorporated into planning procedures in the form of tolerances. The obvious desirability of such modifications in approach to scheduling is to remove some of the justifiable psychological barrier to giving precise commitments on inherently variable events and to eliminate the use of extreme estimates by substitution of a range of time between them. The challenge is to achieve this end without destroying the basic simplicity of the Gantt Chart and its subtle effectiveness in establishing performance goals.

THE PROBABILITY MODEL

For clues to a means of handling uncertainties in forecasting a sequence of events, let us examine the behavior of repetitions of a simple chance event of extreme degree of uncertainty, one which may require as many as six days, and as few as one day with equal a priori probability of completion on any day within the range. If the event is repeated (with its outcome not influenced by the outcome of the first event), the combination of the two events may require as many as 12 days and as few as 2 days. The probability of completion on either of the extremes, however, while 1/6 in the case of the single event, is 1/36 for the combination of two events, and $1/6^n$ for the nth repetition. While the probabilities of the extremes are diminishing exponentially, the probability of completion on the midday of the range of possibilities remains nearly constant. A plot of the probability of completion on any day against time for a number of repetitions gives a set of tangent polynomials of degree $(n\text{-}1)$, which by the fourth event have converged (within the readability of the graph) to the Gaussian or normal probability distribution. Such a graph would permit the gratifying observation that extremes of the range of possibilities rapidly diminish as probable outcomes; but the forecast of completion *on* any given day is generally of less interest in a schedule than completion *on or before* that day. The probability of completion *by* any given day is expressed as the sum of probabilities for all days up to the given day. The plot of these cumulative probabilities against time is shown at the top of Figure 2.

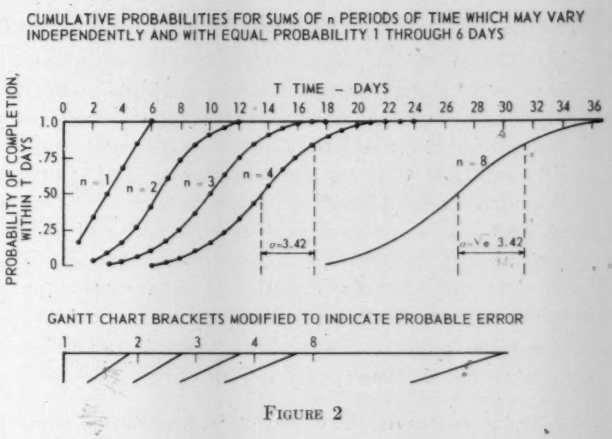

FIGURE 2

The form of the curve is basically that of a Gantt Chart for one operation, the major difference being that the right hand leg of the forecast bracket, instead of indicating a single date, is sloped to cover the range of all possible outcomes and their associated probabilities. The curves, as plotted, bracket the completely "safe" forecasts; for, by hypothesis, completion of the nth repetition will fall between n and $6n$ days. But this range, or tolerance, is too great to be of scheduling value, and is in fact no better for the nth repetition than for the first. However, if one is willing to assume the risk involved in ignoring the possible but improbable extreme outcomes, the curves provide the basis for making this a truly calculated risk.

Note that while the mean and extreme times required increase proportionally with the number of repetitions, n, the tolerance or range of time between any two probability limits increases at a lesser rate, becoming proportional to $\sqrt{n}$. For any specified level of risk, the tolerance required about the mean, as a percentage of the mean, will decrease as $\sqrt{n}$. As an example, note on Figure 2 the tolerances which would have to be allowed to cover all but 1/6 of the possible outcomes. (The risk of one in six is convenient for our model; and it carries some associations which give it significance by virtue of being "the odds" in Russian Roulette.) The mean, or probable, completion date of the eighth repetition is the 28th day; and the probability of completion by the 32nd is the specified 83.3% (5 out of 6). The tolerance of four days, or 14% of the mean, is quite manageable in view of the fact that any single event in the sequence would have a corresponding tolerance of 1½ days or 43% of its mean requirement of 3½ days.

In spite of the improvement in relative tolerances, the absolute tolerance about a mean completion date continues to increase with the number of repetitions. It follows categorically that the precision of the forecast can always be increased by reforecasting after passage of time; for this, in effect, eliminates the influence on the future of what were uncertainties in the past.

APPLICATION OF TOLERANCES TO REAL SITUATIONS

From a study of forecasting outcomes of a purely chance event, there emerges a set of concepts which can be applied to forecasting in a real situation, that is, one in which uncertainties are off-set to some extent by the ability of those who use the schedule to shift resources and control rates of progress. These concepts are for the most part, simple rewordings of some familiar properties of probability distributions. Referring to Figure 3, which gives the probability of completion of an operation by any time, T, we can define the following:

1. Probable Duration or Completion Time—A date by which the probability of completion of the operation is 50%; that is, just as likely to be complete as not.

2. The probable error—that range of time about the expected completion date within which probability of completion is 50%. This concept is useful as an indication of the precision of the estimate. At the bottom of Figure 2, the probable error (the range between 25% and 75% probability of completion) is used as the basis for drawing a set of Gantt Chart brackets.

3. The acceptable risk tolerance—that range of time outside of which the probability of outcome is small enough to be ignored with specified risk. This is shown in Figure 3 for a 5% risk tolerance. This concept introduces a quantitative basis for use of the Gantt Chart as a control, for if exceeding the risk tolerance is interpreted as failure in performance or estimate of performance, it can be the signal for remedial action. Since the Gantt Chart itself will show only the tolerances about the end point of each phase, a set of charts showing risk tolerence (or control limit) will be needed, one for each operation, to supply necessary information at the time of review.

The most attractive property of the probability model, that the tolerance for completion of any phase is the square root of the sum of squares of all phase tolerances up to and including the phase under consideration, can be used only with extreme caution in assuming independence of estimating time required from one phase to another. It is quite possible that an environmental change might influence performance in many or all operations in the same way, with consequent bias to the entire program. Fortunately, the estimates in the form of probable duration and probable error as defined yield a priori probability of an equal number of phases ahead and behind

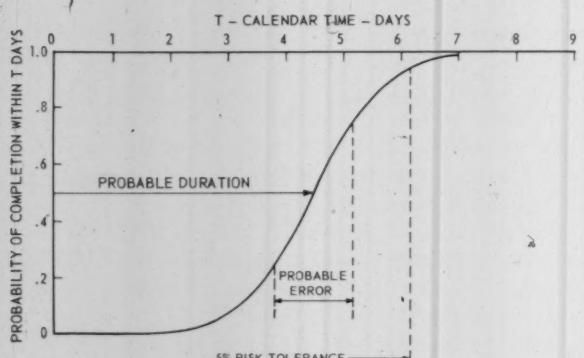

FIGURE 3

schedule. Upon a review date, the actual number of phases ahead and phases behind schedule can be tested for a statistically significant difference from each other. Should such a difference exist, the procedure for estimation is suspect and the direction of the correction is indicated.

One may conjecture that the probability based concepts stated above have always influenced the practice of time and cost estimation intuitively. Most of us, upon having an outcome fall quite close to our estimate, have conceded the result to "sheer luck". We would have been satisfied with a greater difference, and the threshold of satisfaction is an intuitive expression of probable error. Similarly, estimates upon which action is based in a competitive situation must deliberately ignore some possible contingencies; and the decision of acceptable risk corresponds to the risk tolerance in scheduling. Unless a considerable body of data is available for derivation of expected times and the pattern of deviations from them, intuition must continue to supply the estimates of tolerances used in planning. Perhaps the immediate value of the concept of probability based tolerance is that is furnishes the basis for systematic recording and analysis of data from experience in planning and review which will yield in the long run a set of quantitatively deduced tolerances.

CONCLUSIONS

This presentation has defeated its purpose if preoccupation with probability has drawn attention from the primarily psychological origin of the need for tolerances in scheduling. In research, for example, the imposition of a time schedule is often resisted as being incompatible with free inquiry in uncharted areas. Yet however obscure the ultimate effort which may be required for solution of a broad problem, the decision to attack that problem forces the allocation of time, facilities, and personnel to certain avenues of approach. The argument that scheduling specific plans impedes flexibility and freedom stems from the fear of greater reluctance to alter a written goal than an unwritten one. Properly used, a scheduling system facilitates the introduction of change, for it reveals immediately the effect of a change in one operation on concurrent operations and on the program as a whole.

Figure 4 shows an early attempt to express the first year scope of work listed in a current research contract program in Gantt Chart form. Note that tolerances have been applied to some time estimates and not to others. The assumption here is that the uncertainties in some of these activities are small in relation to the time which can be allocated to them; consequently it is feasible to assign a fixed completion date to them. Note also that the first review date has been assigned at the outset to assure follow up.

To the Operations Analyst, the story of the origin of the Gantt Chart is of particular interest as a case history in the relations of consultant to the executive and staff. In

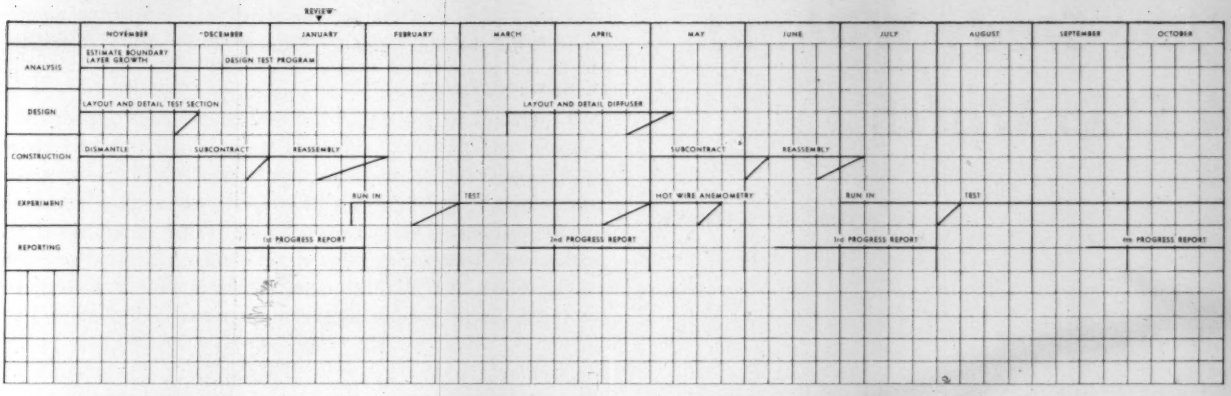

FIGURE 4. First Year Program for Research in Turbulent Flow in a Cylindrical Space of Revolution.

this case, the need for a procurement scheduling system was conceived by the executive; the problem was solved by Gantt as consultant; and the resulting system was ultimately carried out by staff. But Gantt did far more than conceive the system. He maintained a guiding influence in the first applications of the technique and creation of the staff necessary to carry on the work. It is apparent from his biography that much of the early work had to be fought through against opposition strong enough to cause us to consider what the fate of the system might have been had Gantt's performance in the consultant role been any less dynamic.

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Time Study Without A Stop Watch[1]

by **JOHN M. KMINEK**[2]
Captain, United States Air Force

THE STOP WATCH has been the predominant timing device for time studies since the days of Taylor. The familiar stop watch, time study board, paper, and pencil have been and will continue to be useful tools of the time study analyst. However, in some industries and under certain conditions, time studies with the stop watch are impractical or even impossible. The timing of a succession of very short elements is difficult and tends to be inaccurate with the stop watch. Authors, such as Niebel (2), generally acknowledge that .04 of a minute is the minimum practical length for such elements. Other conditions, such as the absence of adequate light (in darkrooms of photographic film manufacturers and processors), make it nearly impossible to collect adequate time study data by the time-honored stop watch method. Eastman Kodak Company uses a portable tape recorder in conjunction with infra-red viewers for operations conducted in areas where little or no light is available. Constant tape speed and tape length are the most important considerations in the Kodak application of tape recorded time study data (1).

Collecting time study data, essentially, consists of three operations on the observer's part; observation and rating of the worker, reading of the stop watch at the break-points between elements, and the recording on paper of the times obtained together with other appropriate information. Thus, the observer's attention must be divided, to some extent, among these three functions. If the latter two functions are eliminated from the actual data collection procedure, the observer may then devote all of his attention to the operation being studied, and thereby, obtain a more representative measure of the elemental times involved and a better rating. This would be most valuable where a task consists of short successive manual elements and requires an accurate time study, or where conditions do not permit ordinary stop watch methods.

A NEW METHOD

A method which might be used under appropriate circumstances involves the use of a small and compact electronic unit and a portable tape recorder. The electronic unit emits a stable series of spiked pulses at a constant time interval. This uninterrupted series of pulses furnishes the time reference or time base. Another circuit in the same unit superimposes a tone upon the time base to mark break-points between elements, or to mark the whole of alternate elements, when a hand-held, push-button switch is depressed. This output information of the electronic unit is introduced into the tape recorder through an appropriate phonograph-jack receptacle on the recorder. Verbal information is recorded simultaneously, when desired, through the microphone receptacle on the tape recorder.

Since the output of the electronic unit includes the time reference, constant tape speed is not important. Element times are obtained by counting pulses between break-points denoted by the beginning of the tone if the tone is used merely to mark those break-points, or by counting pulses separately for whole elements marked by a continuous tone and the alternate adjacent elements identified by the absence of the superimposed tone. It was found desirable to record the actual time measurement information at a high tape speed (7½ inches per second) and play back this information at a slower speed (3¾ inches per second) during analysis in order to enable the analyst to count the time base pulses between element break-points easily.

A complete verbal work place and job description may be recorded in addition to the actual time study measurement information supplied through the electronic unit. The element number may be recorded verbally (or coded) between break-points to insure identification of elements. Any unusual occurrences or delays may also be verbally described in detail as they occur while the observer's undivided attention remains focused on the worker and the task being performed. Verbal information recorded simultaneously with the time measurement data at a high speed is, of course, unintelligible at the slower speed play back, however, the time measurement data remain undistorted and clear. Such verbal information requires additional play back at the same tape speed as that at the time of recording. Transcription of all the data collected on tape may be made to a written record by the analyst or a clerk at the appropriate time and place.

THE ELECTRONIC UNIT

The electronic unit presented in this article is simple to construct, relatively inexpensive (approximate net cost, $40), and reliable. The assembled electronic unit measures 9½ inches by 5 inches by 5½ inches. In the interest of portability, the unit has been mounted in a metal carrying case, as shown in Figure 1. The total weight of this unit

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[1] The contents of this article are the personal views of the author and are not to be construed as a statement of official Air Force policy.

[2] The author is indebted to George H. Brooks, Assistant Professor of Industrial Engineering, James W. Barany, Department of Industrial Engineering, and D. C. Sarkar, Department of Electrical Engineering, Purdue University, for valuable advice and constructive criticism concerning this experimental project.

(including the carrying case) is approximately 8 pounds.

This electronic unit was tested several times at an electronics laboratory over a three month period. The all important series of time base pulses was observed on an oscilloscope and found to be stable in all respects, both with and without the superimposed tone. The wave form of the time base is shown in Figure 2. The stability of the time interval between pulses was also checked over extended periods of time by counting pulses per second with a Universal Eput and Timer.[3]

Basically, this prototype unit is a combination of three circuits:

1. A blocking oscillator trigger generator circuit (3).
2. A modified code-practice oscillator circuit (4).
3. A voltage regulator circuit utilizing a 340 volt rectified power supply.

The 300 volt regulated d-c output of the voltage regulator circuit is utilized by the trigger generator circuit (oscillator circuit No. 1) to maximize the stability of the time base while 340 volt unregulated d.c. current is utilized by the modified oscillator circuit No. 2, as shown in the schematic diagram (Figure 3).

The repetition rate of the time base pulse may be varied through a wide range by making suitable changes in the values of the grid capacitor (C 4) and grid resistor (R 4). The value of the grid capacitor controls both pulse length and repetition rate while the value of the grid resistor controls only repetition rate. The potentiometer (R 5), also in that grid circuit, controls the pulse repetition rate within a limited range. The components listed in Figure 3 provide a pulse repetition rate which may be varied from approximately 298 to 346 pulses per minute by adjustment of R 5. Sw 1 (in oscillator circuit No. 2) is the hand-held push-button switch[4] which is utilized to provide break-point information. The output of the electronic unit is connected to the tape recorder through a cable of appropriate length.

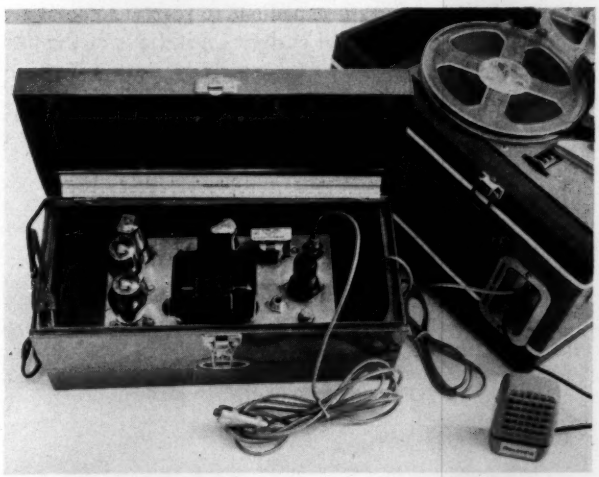

FIGURE 1

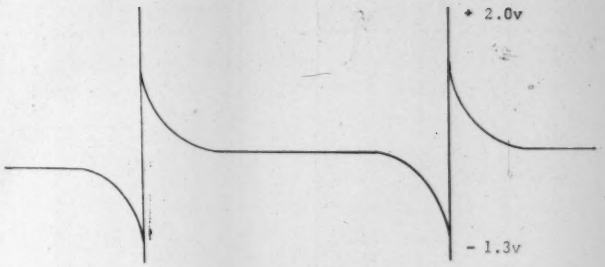

FIGURE 2

TRIAL APPLICATION

The electronic unit was utilized in a simple experiment with a portable tape recorder[5] which was available. The purpose for this trial application of the new method was to provide a general indication as to whether the electronic unit might be a practical replacement for the stop watch under appropriate circumstances.[6] Statistical validation of the electronic method will require a far more intensified study under well-controlled laboratory and actual industrial conditions.

A two-cycle film loop of a drill press operation was prepared. The drill press operation was projected at a constant speed on a shadow box screen while several individuals accomplished both a stop watch time study and the electronic unit time study of this filmed operation. The actual time for each element in the drilling cycle as projected was computed from the wink counter readings shown on the film and the total time for ten cycle repetitions. The tape recorded and stop-watch data were then compared to the computed time data.

The actual computed times of the elements varied between .043 and .060 of a minute. The average of each elemental tape recorded time was closer to the actual computed elemental time by a significant amount. The stand-

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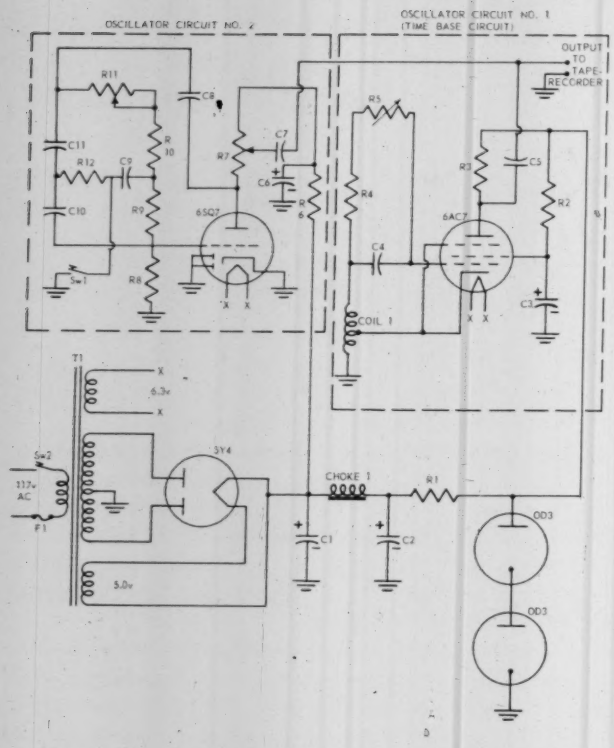
[3] Universal Eput and Timer, Model 7360, Purdue University. The pulse repetition rate was adjusted to 300 pulses per minute (5 per second) to increase ease in counting at half speed play back, to simplify conversion into hundredths of a minute, and to facilitate the Universal Eput and Timer laboratory check.

It should be noted that electronic laboratory facilities are not required for calibration of the unit. The unit may be calibrated for all practical purposes by making the appropriate adjustment after counting pulses during a half speed play back of a two minute cycle recorded with reference to the second hand of an electric clock. Several such observations and adjustments may be necessary to complete and insure calibration.

[4] Sw 1 is connected to the electronic unit by a long low-resistance cable. A step-type switch could be used to advantage in place of the push button switch to mark the whole of alternate elements.

[5] Wilcox-Gay "Recordio," Senator Model-752 Series.

[6] Time limitations and other commitments prevented the author from pursuing the project beyond a simple trial of the prototype model. The promising aspects of the new method led to early publication with the hope that interested entities would continue research and development.



NOTE: The circuit components used in these circuits were the most readily available and appropriate substitution is permissible (i.e. the 600v capacitors listed could just as well be 450v. capacitors, etc.).

The values of R 4 and R 5 control pulse repetition rate (p/sec.).

The value of C 4 also controls pulse repetition (and pulse duration).

For the values shown the p/sec. may be adjusted by the potentiometer R 5 within the range desired (approx. 5/sec.).

C 1—8uf, paper, 600v.
C 2—8uf, paper, 600v.
C 3—0.1uf, paper, 600v.
C 4—0.1uf, paper, 600v.
C 5—0.01uf, paper, 600v.
C 6—20uf, paper, 600v.
C 7—0.003uf, paper, 600v.
C 8—0.01uf, paper, 600v.
C 9—0.002uf, paper, 300v.
C 10—0.001uf, ceramic, 300v.
C 11—0.001uf, ceramic, 300v.
Choke—7 Henries @ 50 ma. dc resistance 550 ohms.

R 1—3000 ohms, 5 watts.
R 2—56,000 ohms, .5 watt.
R 3—10,000 ohms, .5 watt.
R 4—1 megohm, .5 watt.
R 5—25,000 ohms, potentiometer.
R 6—470,000 ohms, .5 watt.
R 7—100,000 ohms, volume control potentiometer.
R 8—2.2 megohms, 5 watt.
R 9—270,000 ohms, .5 watt.
R 10—100,000 ohms, .5 watt.
R 11—1 megohm, pitch-control potentiometer.
R 12—27,000 ohms, .5 watt.

Coil—21 turns, #22 C-W, Dia. ½", tap at turn 7.
Sw 1—Hand-held push-button switch.
Sw 2—Line switch.
F 1—lamp. 250v. fuse.
F 1—340-0-340 volts @ 70ma., 6.3v @ 2.5amps., 5.0v @ 2.0amps. Power Transformer.

FIGURE 3

ard deviation of the elemental stop-watch readings was in the proximity of .010 of a minute as compared to .005 of a minute for the electronic tape recorded data. However, it must be emphasized that the stop watch was read to the nearest .01 of a minute while the recorded electronic data were readable to .0033 of a minute.

These preliminary results indicate that the electronic method may be a feasible alternate method of collecting time-study data, that it can be a more accurate method, and that the data collected may be more consistent. However, analysis of the data also emphasized, what seems to be the greatest disadvantage of this new method at its present stage of development, the need for extra manual operations to transcribe the tape recorded data and compute the times sought.

FUTURE PROSPECTS

The electronic method of collecting time-study data furnishes a basis for several interesting possibilities for future research and development:

1. Transistorization of the electronic unit is possible with considerable reduction in size and weight. Development of such a small battery-operated electronic unit would eliminate the need for an external power source. Compact battery-operated tape recorders are currently available for purchase. Such versatile equipment would be of use in locations where an external power source is unavailable and for applications which require mobility.

2. Counting of time base pulses within elements is possible by electronic or magnetic counters. Either method of counting time base pulses would eliminate the necessity for low-speed play back which is required for manual counting and allow use of a higher time base pulse repetition rate to increase the time resolution of elements. The additional equipment might be justified in cases requiring analysis of large amounts of electronic time-study data.

3. Coded element identification might be utilized during origination of the data in order to permit use of the tape record as an input to a data processing system. Thus, large amounts of time-study data could be originated and converted to a suitable form for analysis without recourse to manual processing.

CONCLUSION

In conclusion, it seems expedient to review some of the significant advantages and current limitations of the presented electronic method of time-study data collection.

Advantages:

1. The ability to time shorter consecutive elements than is generally possible utilizing the ordinary stop watch method.

2. The ability to collect time-study data under conditions not conducive to collection by the stop-watch method.

3. The ability to collect more representative data due to the observer's undivided attention in observing the operation.

Other possible advantages:

4. Less worker distraction of the type caused by the observer writing on a time-study board.

5. Greater labor union acceptance due to the modern scientific approach to this method.

Present limitations:

1. The need to transcribe the recorded data involves extra clerical operations.

2. The size and external power requirement of the prototype unit presented are less than optimum.

3. The method does not avoid the limitation due to human reaction time inherent to stop watch time study.

It must be reiterated that the primary purpose of this article is to present a new method of time-study data collection and the working model of the electronic unit making that method of data collection possible. Future prospects for improvements in both method and model have been indicated. Also, the need for statistical verification of the superiority of this method over the time-honored stop watch method has been indicated prior to general acceptance of any increased accuracy claims. It is hoped that interested individuals, or companies in need of such a method of time-study data collection, consider the possibilities of tape recording electronic-timed elements and report the results of any further research and development in this area.

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Hospital Work Sampling with Associated Measures of Production[1]

by **ROBERT J. CONNOR**[2]

The Johns Hopkins University

IN THE EARLY 1950's work sampling was introduced into many areas as a work measurement technique. It has been used successfully in situations in which it had been thought impossible to obtain adequate measurements of work. The functions of the work sampling studies have varied widely. In one text twelve different uses are cited, from verification of time study allowances to utilization of personnel and equipment (3).

Among the new areas into which work sampling has been introduced is the hospital. In 1954 the Division of Nursing Resources of the United States Public Health Service issued a manual which recommended the use of work sampling "to determine how nursing and other unit personnel divide their time . . ." (6 p. 1). In addition to the manual there have been several work sampling studies carried out in hospitals. Wright in 1954 reported a study performed at Harper Hospital in Detroit (5). Cramer in 1956 described a work sampling study conducted at The Johns Hopkins Hospital (2). Torgerson in 1959 presented work done at the Ohio State University Hospital (4). These studies, essentially, sought to determine the ways in which nursing personnel (i.e., registered nurses, charge nurses, and general staff nurses; student nurses; practical nurses; and nursing auxiliaries, nursing aides, and orderlies) spend their time. From these work sampling studies it was hoped that improved utilization of nursing personnel could be effected.

MEASURES OF PRODUCTION

In the manual and in the work samplings in hospitals there has been a common failing, that is, there has been no attempt to obtain quantitative estimates or measures of factors associated with the work load of nursing personnel. There have been no measures of daily fluctuation

[1] The work described has been conducted at The Johns Hopkins Hospital with support from the United States Public Health Service Research Grants GN-5537 from the Division of Nursing Resources and W-167 from the Division of Hospital and Medical Facilities.

[2] Now at Graduate School of Business, University of Chicago.

in the following:

1. The number of patients (census) on the unit.[3]
2. The number of nursing personnel hours scheduled (hours available).
3. The amount of direct patient care to be given.

Since these factors are commonly thought to affect greatly the work load on the unit, it follows that the manner in which the personnel spend their time may be affected. Certainly, the results of work sampling studies would differ between days of high direct patient care and days of low direct care, even if only with respect to the time spent specifically in direct patient care.

Why the first two of these measures were not used is not known to the author. It may be that the census and hours available were held constant for the duration of the study. Or, perhaps, the census and hours available varied so slightly that they were considered constant. The third measure, the amount of direct patient care, probably was not used because there was no quantitative estimate of direct patient care available.

The lack of these measures does not make work sampling valueless, but does limit the interpretation of results.

WORK SAMPLING AT THE JOHNS HOPKINS HOSPITAL

At The Johns Hopkins Hospital the Operations Research Division has undertaken a study entitled "The Optimal Organization and Facility for a Nursing Unit," which was initiated in 1957 with support from the United States Public Health Service. In this project a patient classification system has been developed (1). This classification system divides the patient population into three groups, viz., Class I patients, Class II patients, and Class III patients. Associated with patients in each class is a distribution of the amount of time spent with the patient in the performance of direct patient care.

An estimate of the direct care load is obtained simply by summing the product of the number of patients in each class by the class' expected care time. This system permits the number of hours of direct patient care given to be estimated with accuracy and facility. This estimate is called the "index."

In order to determine the relationships between the time nursing personnel spend in productive activities, the amount of direct patient care to be given, the census, and the hours available, a work sampling study was conducted. For reasons related to the overall research study the observations were (1):

1. Made on ward medical units.
2. Made between 7:00 a.m. and 6:00 p.m.
3. Taken on 22 random visits to the unit.
4. Made of registered nurses; student nurses; practical nurses; and nursing auxiliaries.
5. Made for 32 unit days.
6. Classified into the following categories:

[3] The ward is the basic hospital organization unit.

I. PRODUCTIVE ACTIVITY

A. *Direct Patient Care:* any activity requiring contact with a patient in a ward or an activity which would, if patient were present, be in contact with him.

B. *Indirect Patient Care:* any activity in preparation for or in completion of direct patient care.

C. *Paper work:* any activity concerned with writing or reading of records or other hospital matter.

D. *Communications:* any activity of oral communication in line of duty.

E. *Other:*

1. Patient Escorting: any off-ward activity connected with transporting of patients.
2. Errands: any off-ward activity connected with procurement or delivery of hospital materials.
3. Clean Up: any activity with the purpose of cleaning or tidying up, other than as part of Direct Patient Care, or Indirect Care.
4. Travel: any activity on the ward in which personnel were moving with an indiscernible purpose.

II. NON-PRODUCTIVE ACTIVITY

A. *Personal Time:* all activities not previously defined.

In performing the study a total of 4,576 individual observations were made, an average of 143 per unit per "day."

RESULTS

The results of analyzing the data without regard for the associated measures (census, hours available and index) are shown in Table 1. From these results it appears that on a ward about 19 hours are spent in patient care and 18 hours in non-productive activity on each "day." If measures of production are used the analyses give quite different results. As an example, when the index is high (an average of 27.3) the results (Table 2) show an average on each day of 27 hours of direct patient care, versus only 14.5 hours of direct patient care when the index is low (an average of 14.8). Conversely, non-productive time is 12.3 hours and 18.5 hours respectively.

TABLE 1

Overall Tabulation for Work Sampling

Activity	Number of Observations	Percent Occurrence	Average Hours per Day
I. Productive Activities	3412	74.6*	53.1*
A. Direct Patient Care	1206	26.4	18.8
B. Indirect Patient Care	794	17.4	12.4
C. Paperwork	526	11.5	8.2
D. Communication	627	13.7	9.8
E. Other	259	5.7	4.1
II. Non-Productive Activity	1164	25.4	18.1
Total	4576	100.0	71.2

* Discrepancies due to rounding errors.

TABLE 2

Comparison of High Index Days versus Low Index Days

Activity	High Index (average of 27.3) Average Hours per Day		Low Index (average of 14.8) Average Hours per Day	
I. Productive Activity	62.5		46.5	
A. Direct Patient Care		27.0		14.5
B. Indirect Patient Care		14.5		12.1
C. Paperwork		9.6		8.0
D. Communication		7.3		7.9
E. Other		4.1		4.0
II. Non-Productive Activity	12.3		18.5	
Total	74.8		65.0	

The conclusion may be drawn from this that, as the direct patient care load increases, the time spent in direct patient care increases and the time in non-productive activity decreases. An interesting feature of the results of this analysis is that the high index days, even with a greater number of hours available, had less time in non-productive activity.

Analyses such as this made it evident that significant relationships exist between the way in which nursing personnel spend their time and the measures of census, hours available, and the index. This in turn suggested that regression analyses of the data would be of value.

A computer program in which the regression analysis is performed step-wise was used. The program first brings in the most important variable, after that variable is accounted for, the most important variable of those remaining is handled, and so on.

The step-wise regressive equations and the correlation coefficients (R) for the regression of the time in all productive activities ($P.A.$) on the three variables, census (x_1), hours available (x_2), and index (x_3) are shown below.

Step 1 $P.A. = 26 + 1.1x_3$

$R = 0.78$

Step 2 $P.A. = 11 + .29x_2 + 1.0x_3$

$R = 0.89$

Step 3 $P.A. = 17 - 25x_1 + .29x_2 + 1.0x_3$

$R = 0.90$

Note that the addition of x_1 is not significant.

From these equations it may be concluded that time required for productive activity varies significantly with the index and also that the hours available significantly affect the time spent in productive activity. It is evident that after index and hours available have been taken into account the census has little effect.

A regression analysis of the time devoted to direct patient care on the three variables indicates that the index is the only significant factor. This result is of some interest for it means that nursing personnel give a standard level of care regardless of how much care is to be given and how many hours are available. This and all other conclusions apply over the ranges of the variables observed in the study. An examination of these ranges has shown that the values of the variables fall outside the observed ranges infrequently. Thus, the conclusions are valid over the normal ranges of the variables under discussion.

One last point to be mentioned concerns the insight into the value of labor-saving equipment and procedures gained from results of the analysis. An equation for time spent in non-productive activity ($N.P.A.$) can be found by subtracting the equation for time in productive activity from hours available. If this is done, using the equation in the second step of the productive activity regression analysis, the following is obtained.

$$N.P.A. = -11 + .71x_2 - 1.0x_3$$

This indicates that as the hours available increase, non-productive time increases. Hence, if labor-saving devices are introduced the personal time saved will not go into direct care but into non-productive activity. The conclusion is that in order to benefit from labor-saving equipment and procedures they must be introduced so that the number of nursing personnel can be reduced simultaneously.

CONCLUDING REMARKS

Some of the specific conclusions from these studies have been given. For a fuller discussion of the study and the conclusions the reader is referred (1).

The general conclusion from the work sampling is that the quantitative measures used permit the data obtained to be analyzed meaningfully. When these measures are used insight into the manner in which nursing personnel spend their time is obtained and the conditions under which the study was conducted are known. This last point is quite important. It is, some believe, the least that can be expected of any study. However, as mentioned earlier, previous studies in the hospital have not presented reliable quantitative estimates of the conditions under which the studies were made. These or similar measures may be used with work sampling in other hospitals and elsewhere, as a desirable refinement in analysis.

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The Application of Manufacturing Improvement Curves in Multi-Product Industries

by PAUL F. WILLIAMS

Industrial Engineer, United Control Corporation

THERE have been several recent articles on the various applications of the aircraft industry's "learning curve." However, it is felt that the need for a clear presentation of a correct, simple method for applying Manufacturing Improvement Curves to short run, multi-product industries has not been met. The aim of this article is to offer a practical, accurate, and usable procedure for meeting this need by answering the following questions:

1. Why use Manufacturing Improvement Curves at all?
2. How can Manufacturing Improvement Curves be developed for specific products and companies?
3. What is the correct method of applying Manufacturing Improvement Curves?

As background for answering these questions a review of the traditional concepts of Manufacturing Improvement Curve theory is needed.

REVIEW OF TRADITIONAL CONCEPTS

The central idea in Manufacturing Improvement Curves, Manufacturing Experience Curves, Manufacturing Progress Curves, or Learning Curves, no matter by what name they are called, is that the unit cost to build a product decreases at a predictable rate as the quantity increases. This property is the basis for estimating production costs and has been verified empirically in several instances (1) (2) (3) (4) (5) (6) (7). Specifically, the theory is that the labor cost per unit, hereafter called unit cost, is reduced by a constant percentage as the production quantity is doubled. Graphically, this unit cost approximates a straight line on log-log coordinates (Figure 1).[1] The aircraft industry's Manufacturing Improvement Curves feature a linear cumulative average cost line (Figure 2). However, evidence gained from a thorough analysis of historical cost data at United Control Corporation indicates that the linear unit cost curve of Figure 1 is more appropriate when applied to short run, multi-product industries.

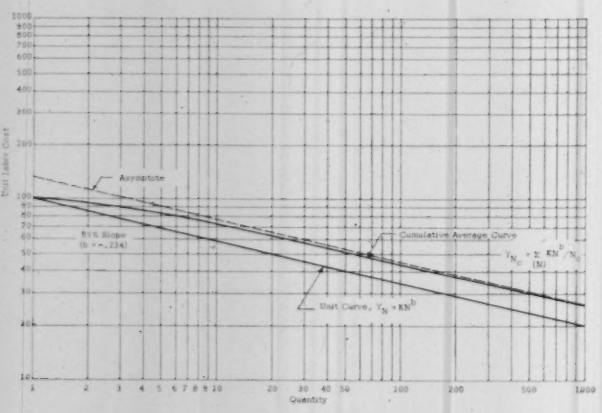

FIGURE 1. Manufacturing Improvement Curve Linear Unit Curve Model.

WHY USE MANUFACTURING IMPROVEMENT CURVES?

Here are five reasons why Manufacturing Improvement Curves are beneficial:

1. Enable the systematic, consistent, and objective prediction of manufacturing performance.
2. Can be used in estimating average costs of both initial quantities and follow-on quantities.
3. Are a graphic technique and simple to use.

[1] An assumption made in this article is that the unit cost curve has a formula $Y_N = KN^b$. The cumulative average cost curve has a formula

$$Y_{N_C} = \sum_{(N)} KN^b / N_C$$

where:

Y_{N_C} = cumulative average unit cost at unit N_C
Y_N = the unit cost at unit N.
K = the cost of unit number one.
N = the quantity $(N \geq 1)$.
b = a measurement of the "slope" of the line.

When plotted on log-log paper, this slope is defined as the unit cost at quantity $2N$ divided by the unit cost at quantity N, expressed as a percentage. The exponent b takes the following representative values:

Slope—%	b
75	—.415
80	—.322
85	—.234
90	—.152
95	—.074

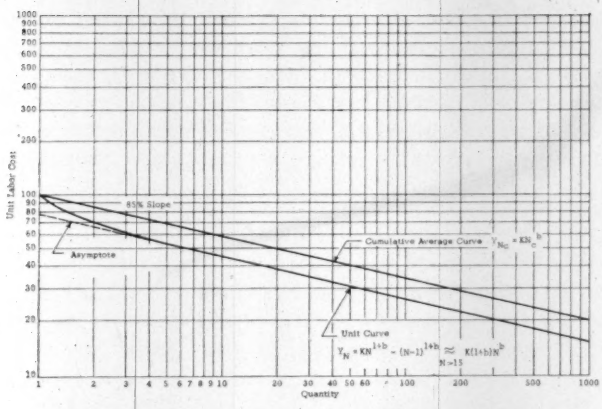

FIGURE 2. Manufacturing Improvement Curve Linear Cumulative Average Curve Model.

4. Can be used as a measurement of manufacturing performance for management control purposes.
5. When applied correctly, minimize the error of estimating.

The problem in estimating is always the same; predict, on the basis of past performance and other related factors, what the cost of a future quantity will be. The method presented here limits the error in the estimate to the accuracy of the estimator by eliminating the error in the method of making the estimate. The traditional application involves assumptions about the mathematics of Manufacturing Improvement Curves which incorporate a known, but correctable, error into the solutions of problems. The method presented here allows these conventional assumptions to be made but corrects the mathematical errors in the answers.[2]

HOW TO DEVELOP MANUFACTURING IMPROVEMENT CURVES

The Manufacturing Improvement Curve is a management tool. Like any other aid it must be used properly for best results. The proper use depends upon the accuracy with which the curve itself is defined.

The first step in developing Manufacturing Improvement Curves is to record data and make calculations. For each product record the work order, date completed, quantity of acceptable units produced, and total manhours or labor dollars involved in production. From this information calculate unit cost (average cost per unit) and cumulative average cost per unit for each work order. Factors relating to changes in production efficiency should be recorded when they occur. Examples of such factors are changes in personnel, manufacturing methods, materials handling techniques, complexity of design, quality of raw materials or components, production rate, or any other changes that might affect the labor cost of the product.

The second step is to plot the cumulative average cost versus cumulative quantity on log-log coordinate paper for each product. As mentioned previously, this line is asymptotic to a line that is parallel to the unit cost line. It is a mathematical fact that the unit cost line cannot be plotted accurately until its slope is known (3). Therefore, the slope is measured from the asymptote of the cumulative average line. In order to get an approximation of the asymptote use one of the following three methods to place a straight line through the plotted data.

1. Straight edge fitted by eye.
2. Overlay graphs for best fit (Figure 3).
3. Method of least squares.

To avoid difficulty due to the curvature of the cumulative average line, use only data related to quantity 15 and higher.

If any of the plotted points seems to vary radically from the trend, refer to the record of changes in the manner of production. The cause of the variation should be indicated by a change that occurred at the same time. The third step is to classify the products. The object is to derive a relationship between different product categories and the value of their Manufacturing Improvement Curve slope. Analyze exceptions to the general trend and check results for consistency. The information obtained in this step is the basis for assigning a slope to a new product for estimating purposes before enough manufacturing data are available to establish its own slope. The following example shows the development of Manufacturing Improvement Curves for several products of a hypothetical company. All facts in this example have been disguised to protect the best interests of the source.

Example 1: Consider a company with 5 products. Their historical costs are shown in Figure 4. Product *A* is a mechanical assembly with extremely close tolerances on all machined parts.

FIGURE 3. Manufacturing Improvement Curve Slopes (Use on Log-Log Coordinates).

[2] The conventional assumption is that the error involved in treating the middle unit as the point which reflects the average unit cost of the whole quantity is negligible. This is called the mid-point hypothesis. The error exists because the hypothesis involves a linear interpolation of curvelinear data. Factors for correcting this error are defined and demonstrated in connection with later examples.

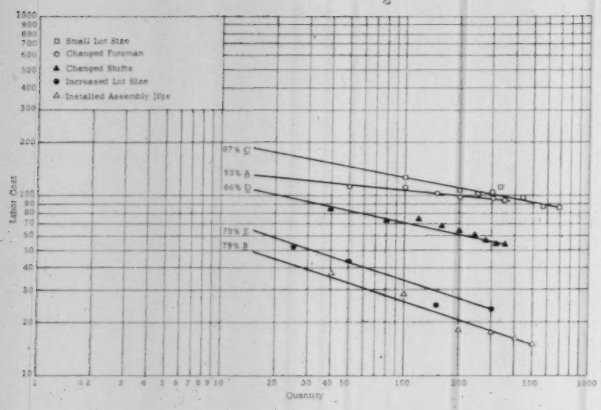

FIGURE 4

Each unit is almost custom made and, even though there is a relatively high quantity, mass production is not practical. Figure 4 shows the plotted cumulative average data with a straight line passed through it to approximate the asymptote.

Product *B* is an electromechanical switch assembly. It has loose tolerances, few parts, and can be mass produced.

Product *C* is an electronic "black box". This unit requires many hours of soldering and hand assembly. Because of the high reliability specified, the assembly has to be carefully and skillfully produced.

Product *D* is very similar to Product *C*. The only differences being that *D* uses less parts and has a printed circuit board where *C* uses soldered wires.

Product *E* is a simple mechanical sub-assembly used on many different products. It is readily adaptable to mass production techniques.

Examination of the Manufacturing Improvement Curves for these products shows that four of them can be grouped into two classes. Products *B* and *E* are similar in complexity, tolerances, and Manufacturing Improvement Curve slopes. In the same manner, products *C* and *D* are similar. Therefore, and here is the value of this step, if a product like *B* or *E* went into production, its slope could be justifiably predicted. The same would be true in the case of *C* and *D*. It should be noted that in all cases the similarity or dissimilarity of slopes is independent of relative labor costs of the different units. The comments made next to the plotted points on the graphs give changes in the regular method of manufacture.

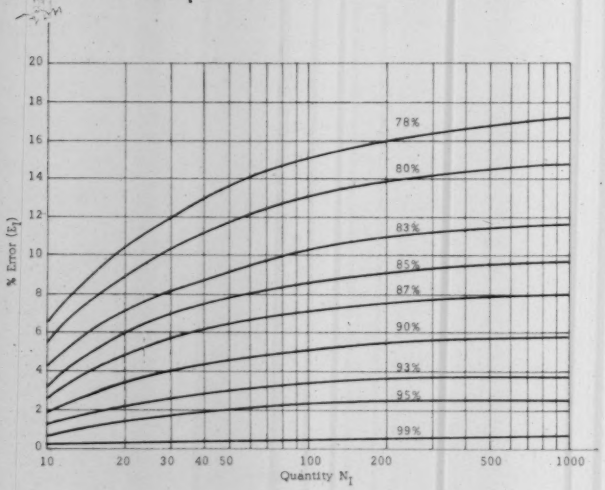

FIGURE 5. Correction Factor for Initial Quantities (Expressed as Percent). Example: $N_I = 200$, Slope = 80%, therefore $E_I = 13.8\%$ or .138.

THE APPLICATION OF MANUFACTURING IMPROVEMENT CURVES

The Manufacturing Improvement Curve for any product is fully defined by the slope and a point on the line. The slope can be determined in the manner previously discussed. The point is an estimated unit cost at some quantity. This estimate point will vary from company to company, depending on such things as; the size of the work order, total quantity to be built, rate of production,

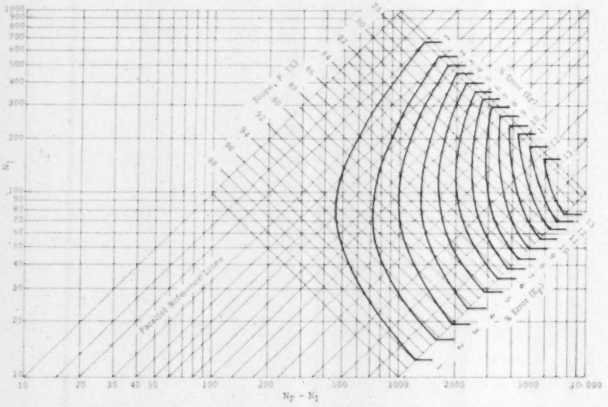

FIGURE 6. Correction Factors for Follow-On Quantities (Expressed as Percent). Example: $N_I = 20$, $N_F - N_I = 500$, Slope = 83%. From the intersection of N_I and $N_F - N_I$ move along the parallel reference lines until the slope is intersected. Relate this point to the curved lines of Constant Error. Thus, $E_F = 7.4\%$ of .074.

and the use of standard times. Estimate points have been used at quantities of 1, 100, 1000, and 10,000 and many places in between. Also, time could be used to mark the estimate point. Thus, the quantity associated with 3, 6, 12, or 24 months' production would establish the point.

Once the Manufacturing Improvement Curve for a product has been established, there are two general classes of its application, "initial quantities" and "follow-on quantities."

An initial quantity is defined as the scheduled manufacture of a product that has either not been previously built or has not been built recently enough to allow some progress down the Manufacturing Improvement Curve. This class of application is shown in examples 2 and 3.

A follow-on application of Manufacturing Improvement Curves is used where the product is currently being manufactured or was built so recently that the Manufacturing Improvement Curve could be considered to have

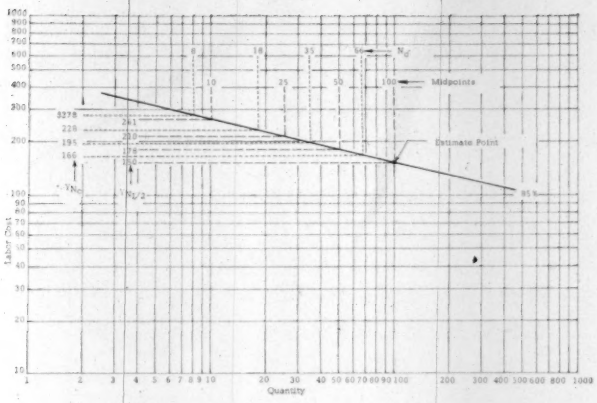

FIGURE 7

been just temporarily interrupted. These quantities are reflected in examples 4 and 5.

Note that the estimate point, estimated unit cost, and Manufacturing Improvement Curve slope for any product can be checked by plotting production data as they occur. The following symbols and equations are used in examples 2 through 5:

Y_N = Unit cost at unit N.
N_I = Initial quantity.
N_F = Initial quantity plus follow-on quantity.
$N_F - N_I$ = follow-on quantity.
N_C = Correct unit for indicating average unit cost.
E_I = Initial quantity correction factor (obtained from Figure 5 by reading the value associated with the intersection of N_I and the appropriate slope.) It is defined as the difference between the correct unit cost and the unit cost at the midpoint of the initial quantity divided by the correct unit cost.
E_F = Follow-on quantity correction factor (obtained from Figure 6 by entering it at N_I, $N_F - N_I$ and moving along the parallel reference lines to an intersection with the proper slope. This point of intersection is near a line of constant E_F.) It is defined as the difference between the correct unit cost and the unit cost at the midpoint of the follow-on quantity divided by the correct unit cost.
MP_F = Initial quantity plus one-half of the follow-on quantity =

$$N_I + \frac{(N_F - N_I)}{2}$$

$$E_I = \frac{Y_{N_C} - Y_{N_{I/2}}}{Y_{N_C}} \qquad \text{Eq. 1.}$$

$$E_F = \frac{Y_{N_C} - Y_{MP_F}}{Y_{N_C}} \qquad \text{Eq. 2.}$$

Example 2: Consider a product that has a Manufacturing Improvement Curve slope of 85%, and an estimated unit labor cost of $150 at unit 100. Determine the average cost per unit when manufacturing initial quantities of 20, 50, 100, or 200 units. This is done by finding the unit cost of the middle unit and applying E_I from Figure 5 using Eq. 1. The information is tabulated in the following manner:

	N_I	$N_{I/2}$	$Y_{N_{I/2}}$	E_I	Y_{N_C}	N_C
1	20	10	$261	.060	$278	8
2	50	25	$210	.079	$228	18
3	100	50	$178	.086	$195	35
4	200	100	$150	.099	$166	66
					ANSWERS	

See Figure 7.

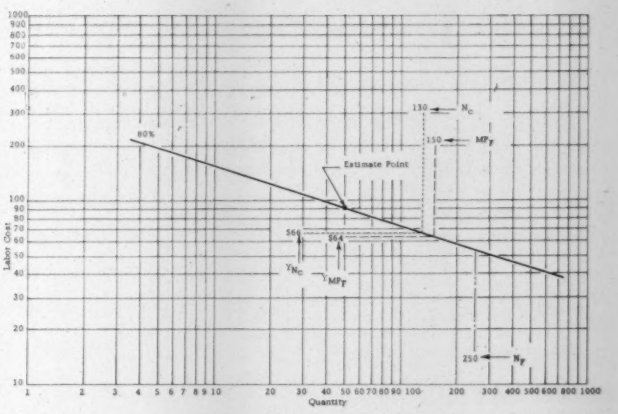

FIGURE 9

Example 3: Consider the same facts as in example 2 and find the quantities that must be built to reach an average unit cost of $200 each, $175 each or $125 each. Use Eq. 1. and the same tabulation form. An approximation of N_I must be used to determine E_I. For this purpose use 3 times N_C and round off E_I to the nearest hundredth.

	N_I	$N_{I/2}$	$Y_{N_{I/2}}$	E_I	Y_{N_C}	N_C
1	72	36	$184	.08	$200	24
2	148	74	$155	.09	$175	46
3	840	420	$112	.10	$125	250
	ANSWERS					

See Figure 8.

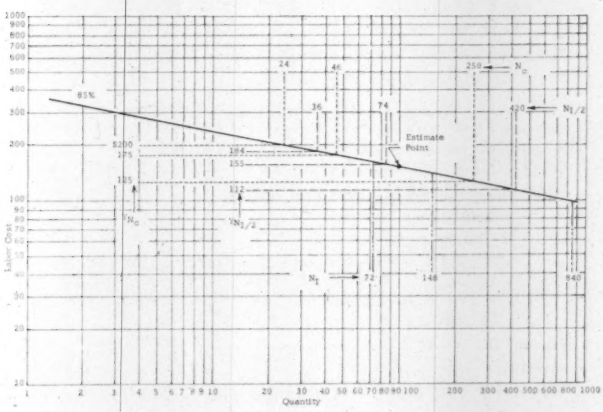

FIGURE 8

Example 4: Consider a product that has an 80% Manufacturing Improvement Curve slope and a cost at unit 50 of $90. Determine the average unit cost of a follow-on quantity of 50, 100, or

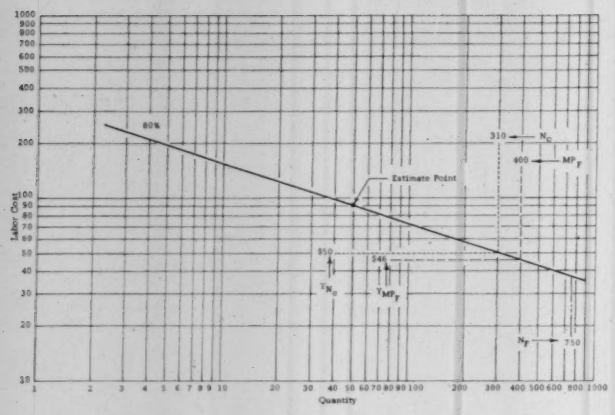

FIGURE 10

200. This is done by finding the unit cost of the midpoint of the follow-up quantity and applying the E_F from Figure 6. Use Eq. 2. and tabulate the information.

	N_I	N_F	$N_F - N_I$	MP_F	Y_{MP_F}	E_F	Y_{N_C}	N_C
1	50	100	50	75	\$80	0	\$80	75
2	50	150	100	100	\$72	.010	\$73	96
3	50	250	200	150	\$64	.028	\$66	130
							ANSWERS	

See Figure 9.

Example 5: Given the slope and estimate point of example 4, find the quantity that must be manufactured to give an average cost per unit of \$50.00 for the follow-on quantity. Use Eq. 2.

$N_I = 50$
$Y_{N_C} = \$50$, $N_C = 310$
$E_I = .07$ (figured at $N_F = 2N_C$)
$Y_{MP_F} = \$50(.93) = \$46$
$MP_F = 400$
$N_F = 750$, or *700 additional parts* *ANSWER*
See Figure 10.

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Estimating Changes in the Research Budget[1]

by **IRA HOROWITZ**

Assistant Professor of Business Administration, Indiana University

IN AN industrial research laboratory successful research management requires the optimal allocation of the research budget among those prospective projects promising a return in excess of that which the stockholders could receive if given these funds as dividends (3). The problem confronting the research director is to maximize the total present value of the various anticipated incomes from the alternative projects, given the research budget constraint within which he must operate (2) (4) (6). It is clearly true, however, that the continuous nature of research will also require some knowledge or anticipation of future research budgets, since there is no basis for starting a project today if the funds to complete it will not be available tomorrow. It is for this reason that multi-year research budgets and planning have frequently been suggested (7). Even where this multi-year planning does occur there may still be deviations from the budget as business conditions change. A rise in sales may encourage management to increase expenditures on research; alternatively, a decrease in profits may necessitate a cut-back in research funds.

In general, the research director could historically have expected his budget to increase exponentially, though the rate of growth might vary between firms (5). This increase has resulted from the combination of rising cost of research plus the increased emphasis placed on research in the past two decades. In this presentation I will examine the extent to which *yearly* variations in the research budget are dependent upon economic conditions within the firm. If such dependency does exist, the research director's ability to anticipate changes in his budget will be improved, and his allocation decisions can be made with greater certainty of the future. The data used to examine this dependency cover 41 firms in 11 different industry categories.[2]

[1] The results in this article are adapted from a paper, "The Changing Research Budget," presented at the Sixteenth National Meeting of The Operations Research Society of America in Pasadena, California.

[2] The original data were collected from a survey of 121 firms, conducted during 1959. In order to obtain extended time series it was necessary to guarantee that the original data and the firms involved would be kept confidential and they are therefore not reproduced here. We arbitrarily chose to eliminate firms providing data for less than 11 years.

THE "PERCENT OF SALES" PREDICTOR

The ability of the statistic "research as a percent of sales" to serve as a "predictor" of research budgets is very slight indeed. Its true importance lies in its giving intertemporal comparisons of managerial desire to spend for research. The way in which this statistic has changed over time can be measured by fitting trend lines to the data for 40 sample firms[3]; i.e., least-squares fits are obtained for equations of the form

$$R_t/S_t = A + aT$$

where R_t and S_t are research and sales in year t, respectively, and T is time measured in years from an origin of $1957 - N$ (where N is the number of observations given in Table 1). The trend coefficient is "a." Table 1 records the results of these regressions.

Although twelve of the trend coefficients are negative, indicating managerial desire to de-emphasize research relative to sales, only two of these twelve are significant (at the 95 percent level of confidence). Of the twenty-eight coefficients that are positive, twenty are significant (at the 95 percent level). While it is apparent that this trend could not keep up ad infinitum, within the relevant range, it seems appropriate to conclude that, by and large, firms are becoming more research intensive, not only with respect to the absolute amount of expenditure, but relative to the size (as measured by sales) of the company as well. Where the trend coefficient is not significant, the R_t/S_t data commonly are subject to wide fluctuations around a mean value given by "A." It thus appears that research as a percent of sales is a reminder and measure of the past rather than a predictor for the future.

ALTERNATIVE CONSIDERATIONS

The level of the research budget over a period of years will depend upon factors such as firm size, market structure, industry growth, and government support. One can also distinguish certain factors that will influence the research budget *in any given year*. The main question here is whether or not these influences take place in a systematic and measurable way. For example, research expenditures in any year may depend upon how much money has been spent on research in the past, since this information will reflect knowledge within the firm, the general size of the firm's research program, and research programs which will be continued. Similarly, the fiscal position of the firm might influence research expenditures. If profits have been high they may provide the funds to be reinvested in research. If profits are low, this too might be a signal to increase research expenditures in order to restore profits to their previous levels. Current sales might also influence the level of research expenditures. Falling sales might press management to cut back research funds

[3] Firm 24 was excluded from this analysis because of erratic shifts in the data resulting from exogenous factors.

TABLE 1

The Trend of Research as a Percent of Sales

Firm	S.I.C. Industry Code	N	A	a	R
1	35	31	.028564	−.000394 (.000198)	−.3412
2	28	30	.025868	.000179 (.000121)	.2651
3	20	28	.000141	.000042 (.000004)	.9123*
4	35	28	.010736	.000373 (.000161)	.4077**
5	35	28	−.000091	.000139 (.000193)	.1315
6	22	28	.020159	.000051 (.000228)	.0426
7	32	28	.008659	.000635 (.000084)	.8252*
8	35	28	.011448	.000375 (.000211)	.3236
9	32	28	.002556	.000196 (.000061)	.5235*
10	26	28	−.000429	.000458 (.000026)	.9578*
11	37	27	.006473	−.000059 (.000087)	−.1324
12	28	27	.017051	.000812 (.000110)	.8229*
13	28	26	.032233	.000539 (.000303)	.3353
14	32	26	.016086	.000753 (.000083)	.8753*
15	39	25	.009300	−.000240 (.000100)	−.4404**
16	35	24	.024673	−.000427 (.000141)	−.5336*
17	28	24	.002234	.001209 (.000157)	.8485*
18	28	24	.041516	.000187 (.000166)	.2292
19	28	22	.013921	.002494 (.000164)	.9555*
20	37	20	.015212	−.000339 (.000370)	−.1918
21	37	20	.035359	−.000889 (.000541)	−.3530
22	33	20	.007357	.000262 (.000084)	.5817*
23	28	20	−.000843	.001614 (.000158)	.9197*
25	33	19	.005088	−.000021 (.000043)	−.1154
26	20	18	.002286	.000287 (.000048)	.8243*
27	28	17	.026469	−.000349 (.000233)	−.3509
28	32	16	.026351	.000467 (.000216)	.4877
29	38	15	.045903	.003553 (.001245)	.6063*
30	33	14	.006181	.000036 (.000124)	.0793
31	35	14	.019185	−.000239 (.000844)	−.0782
32	36	13	.144686	−.002397 (.001604)	−.3962
33	33	13	.001109	.000265 (.000051)	.8324*
34	28	13	.017133	.000687 (.000218)	.6725**
35	28	13	.002089	.000495 (.000097)	.8158*
36	28	12	.010715	.002581 (.000490)	.8464*
37	28	12	.057065	−.001325 (.000591)	−.5602
38	28	12	.053542	−.000434 (.000542)	−.2344
39	32	11	.010544	.001088 (.000229)	.8327*
40	28	11	.018749	.001893 (.000261)	.9022*
41	26	11	.008091	.000755 (.000232)	.7166**

* Significance at the 99% level of confidence.
** Significance at the 95% level of confidence.
R is the correlation coefficient.
The figures in the parentheses are the standard errors of the regression coefficients.

in order to maintain dividends; or, alternatively, might spur increased research to combat further sales declines through product improvement. It is important for the research director to have an understanding of the way these forces will operate in his particular firm.

This can be done by utilizing past data for research expenditures, sales, and profits to measure the causal relationships between these variables. Since rational arguments can be given for increases in research expenditure being caused by either increases *or* decreases in sales and profits (and similarly for decreases in research expenditures), it is important to separate the profits and sales streams into two distinct time series for analysis. One time series should include all the increases in the variable (with the remaining observations taken as zero) and the other, all the decreases (with the remaining observations taken as zero).

One can then set up the hypothesis that changes in research expenditures between any two years t and t-1 will be a function of:

1. Increases in current sales, ΔS_t^+
2. Decreases in current sales, ΔS_t^-
3. Increases in previous profits, ΔP_t^+
4. Decreases in previous profits, ΔP_t^-
5. The previous level of research expenditures, R_t

Using multiple regression techniques to test this hypothesis will require fitting equations of the form

$$\Delta R_t = I + e_1\Delta S_t^+ + e_2\Delta S_t^- + f_1\Delta P_{t-1}^+ + f_2\Delta P_{t-1}^- + g_1 R_t$$

to data from the past history of the firm. The effect of increasing sales or profits will thus be shown by the coefficient e_1 and f_1; the effect of decreases will be shown by e_2 and f_2. Where the effects of, say, increases and decreases in sales were the same, e_1 and e_2 would be equal and there would be a tendency for research expenditures to maintain a consistent ratio to sales.

It is important to note that the regression equation considers profits in the *preceding year* and sales in the *same year* as the potentially influential variables. This is done to allow for the effects on research expenditures of past liquidity, since the research budget is commonly established in the preceding year, as well as the effects of current financial circumstances, since the research budget

TABLE 2

Multiple Regression Relationships

Firm	I	a_1	a_2	f_1	f_2	g	R	F
1	122.340	.00137	.00013	.0395	.6300	−.0240	.2894	.4575
		(.00304)	(.00295)	(.0493)	(.0560)	(.1072)		
2	−224.631	.01458*	.03066	.1163*	−.6619*	.0473	.9236	27.8530*
		(.00329)	(.03943)	(.0364)	(.1510)	(.0315)		
3	33.573	.00004	.00009	.0007	.0063	.0973*	.6699	3.5825*
		(.00015)	(.00041)	(.0053)	(.0065)	(.0240)		
4	−216.239	.01246	−.00854	.0707	.0346	.2189*	.7144	4.5870*
		(.01099)	(.03020)	(.1118)	(.1632)	(.0573)		
5	−570.167	.01053**	−.00220	.0863	.0035	.0531	.6360	2.9889**
		(.00438)	(.00692)	(.0591)	(.0641)	(.0315)		
6	95.890	.00489	−.00785	−.0047	.0059	−.0156	.2451	.2812
		(.00550)	(.00863)	(.0234)	(.0182)	(.0489)		
7	225.097	.00187	.00237	.0275	.0596	.0432	.3107	.4699
		(.01224)	(.04015)	(.0809)	(.1084)	(.0429)		
8	26.980	.00043	.00511	.0051	.0115	.1811*	.8038	8.0331*
		(.00447)	(.00807)	(.0413)	(.0538)	(.0347)		
9	15.296	−.00376	.02361***	.0296	.0036	.0725	.5654	2.0676
		(.00579)	(.01137)	(.0273)	(.0334)	(.0943)		
10	52.663	−.00549***	.01814	.0053	.0192	.1758	.7860	7.1214*
		(.00233)	(.00911)	(.0153)	(.0207)	(.0331)		
11	−472.763	.00211	.00041	.0865*	−.0418	.4478*	.8847	15.1280*
		(.00234)	(.00441)	(.0211)	(.0337)	(.0671)		
12	− 67.326	−.00100	−.00567	.2077**	−.1854	.0519	.6102	2.4910***
		(.00766)	(.01476)	(.0822)	(.1749)	(.0363)		
13	− 45.697	.02454***	−.13666**	.00683	−.1374	−.0225	.6611	3.1060**
		(.01097)	(.04385)	(.0485)	(.1248)	(.0303)		
14	− 57.046	.01237	−.06266	−.1004	.1612	.2580*	.8954	16.1716*
		(.01254)	(.30867)	(.0591)	(.1126)	(.0553)		
15	− 27.317	.00400	−.01790	.0008	.0299	.1226	.4473	.9508
		(.00338)	(.02696)	(.0257)	(.0510)	(.1110)		
16	− 63.605	−.00169	.02803	.0214	.1082	.2977**	.6513	2.6521***
		(.01060)	(.05970)	(.0599)	(.1504)	(.1164)		
17	− 74.975	.00815	.00179	.0857	.0631	.2232**	.7796	5.5789*
		(.00963)	(.01377)	(.1136)	(.2203)	(.0489)		
18	− 50.996	.00058	−.12379	.0643	.1258	.2492**	.9061	16.5118*
		(.01226)	(.16794)	(.1143)	(.1787)	(.0792)		
20	−122.386	.00449	.00190	.2839	−.2965	−.2770	.3838	.5526
		(.00520)	(.00723)	(.2154)	(.3586)	(.1953)		
21	413.477	.00336	.01922	.2932	−.1008	−.1568	.3736	.4544
		(.01797)	(.02519)	(.6941)	(.7965)	(.2419)		
22	22.093	.00119	.00385	−.0668	−.0261	.1281	.5968	1.5492
		(.00217)	(.00293)	(.0459)	(.0470)	(.0586)		
23	29.116	.03783*	−.08071***	−.0954	.1912	0.242	.7787	4.3140**
		(.00864)	(.03399)	(.0689)	(.0876)	(.0436)		
24	4208.618	.03140	.01745**	−.2737	.2179	−.0908	.7334	3.2592**
		(.01775)	(.00627)	(.2378)	(.1344)	(.0885)		
25	12.744	−.00057	.00358	.0176	−.0190	.0125	.6426	1.8286
		(.00068)	(.00246)	(.0089)	(.0142)	(.0551)		
26	−168.931	.00375		−.0409	.0629	.2546*	.8229	6.8182*
		(.00316)		(.0503)	(.0597)	(.0543)		
27	− 93.853	.01357*	−.01331	.0095	.0433	.1946*	.9695	34.4059*
		(.00158)	(.01425)	(.0149)	(.1101)	(.0375)		
28	−145.975	.03228	−.01454	.0106	.0861	.0909	.5335	.7956
		(.01891)	(.15026)	(.0732)	(.1099)	(.1268)		
29	−140.863	.15124	−.46964	−.4115	1.8079*	.2617	.9510	17.0285*
		(.5372)	(.60686)	(.7634)	(.5348)	(.1511)		
30	83.927	−.00551	−.00336	.0019	−.0411	−.2272	.4574	.4232
		(.00533)	(.01111)	(.0250)	(.0454)	(.2222)		
31	− 64.390	.00508	−.02269**	.1639**	−.0155	−.0097	.8631	4.6720**
		(.00529)	(.00642)	(.0509)	(.0847)	(.0975)		
32	−136.524	.17858*		2.2895*	−2.2785**	−.2687***	.9540	20.2470*
		(.02606)		(.4344)	(.7419)	(.0931)		
33	35.052	−.00217	.00171	.0025	.0066	.0224	.6921	1.2872
		(.00103)	(.00086)	(.0066)	(.0095)	(.0813)		
35	− 35.556	.00992	−.00803	.0326	.0559	.1203	.5669	.6630
		(.00900)	(.01285)	(.0483)	(.0897)	(.1821)		
36	−145.240	−.03827	−.00212	.3365	−.4235	.1902	.5358	.4832
		(.03500)	(.02447)	(.3067)	(.3491)	(.1971)		
37	−331.966	.00076	.11946	.0966	−.0926	.1798	.8133	2.3450
		(.01397)	(.30361)	(.1176)	(.1629)	(.0876)		
38	1897.119	−.00765	.05753	.1173	−.0233	−.3404	.6256	.7717
		(.03384)	(.08025)	(.1267)	(.1151)	(.1811)		
39	−128.131	.00325	−.01764	.1162***	−.0934	.0155	.8007	1.7863
		(.00703)	(.01199)	(.0470)	(.0939)	(.0984)		
40	− 16.461	−.00476	−.01746	.0917***	.0882	.1233	.8879	3.7259***
		(.01217)	(.02116)	(.0414)	(.0626)	(.0681)		
41	−106.485	.00490	−.01765	.0071	.0253	.1353	.8678	3.0502
		(.00240)	(.00643)	(.0140)	(.0178)	(.0852)		

* Significant at the 99% level.
** Significant at the 95% level.
*** Significant at the 90% level.

R is the Multiple Correlation Coefficient and F is the Variance Ratio.
The figures in the parentheses are the standard errors of the regression coefficients.

may be flexible enough to permit cutbacks where deemed necessary or permit expansion where financially feasible.

It would, perhaps, be interesting to examine the additional hypotheses that sales in the *preceding year* and profits in the *same year* exert an influence on research expenditures. However, the high correlation between sales and profits of the same year, both independent variables, would make it impractical to deal with both these variables in a single multiple regression.

Equations of the foregoing form were in fact fitted to the data for 40 firms in the sample.[4] The results of these regressions are shown in Table 2. At the 95 percent level of confidence there were four significant e_1's, three e_2's, five f_1's, three f_2's and ten g's. At the 90 percent level of confidence there were six significant e_1's, five e_2's, seven f_1's, three f_2's and eleven g's.

As expressed in the literature, the generally held feeling is that research expenditures are invariant with the business cycle as firms attempt to maintain a degree of constancy in their research program. As such, research acts as a stabilizing influence on the broad category of "investment" as a whole.[5]

Although the results substantially support this claim, distinguishing between the rises and falls in the cycle indicates that there are, within several firms, tendencies to behave asymmetrically in regulating the annual budget to conform to current business conditions. Therefore, the simple linear hypothesis is inadequate to explain the relationship between the business cycle and liquidity, and the annual budget.

Furthermore, these tendencies indicate that such invariance as does exist is more pronounced (though certainly not to a very great extent) with respect to adverse business conditions and unavailability of "current funds" to finance "next year's" research. In only three cases did downturns in sales or profits (significantly in the least squares sense) reflect themselves in decreases in the research budget.

On the upward side, however, there were several (eleven) cases in which increasing sales and profitability went hand in hand with increasing research expenditures, indicating that in these firms the philosophy is to spend as much as the fiscal position of the company will allow.

There is also a "contrary" case reflecting decreases in expenditure when sales increase; and, there are some cases reflecting increases in the research budget when sales and profits decrease. The contrasting management philosophies that one can read into these results are similarly apparent.

On the basis of these results one can draw the following inferences. In research-conscious companies, such as those in our sample, the annual budget *may* be planned on a yearly basis, but if it is, current profitability and business conditions have not in the past been regularizing factors. When such factors have been taken into consideration, it is apparently with a view towards obtaining further funds to extend the budget rather than regarding research as a fringe expense to be cut back when dire times arise. This may be true because the firms *are* particularly research conscious, or because they are, for the most part, prosperous firms that can readily weather any individual storm without immediately deserting the ship. An occasional reaction to support other behavioral patterns has also been noted, but these are seemingly unimportant.

It is also worth calling attention to the fact that where the tendency to increase the research budget in proportion to the previous year's budget was pronounced approximately 20 percent was the figure estimated from the data. A figure of 10 percent might indicate a desire for a moderately increasing budget, and a figure of 45 percent a desire to hurriedly increase operations; but 20 percent seems to be a figure that middle-of-the-road management desirous of adhering to this policy would take..

CONCLUSIONS

Although in the majority of cases considered, yearly variations in research expenditures were not explainable on the basis of the variables considered. In many cases these variations could be explained only by the variables. Even in those cases where causality could not be inferred, there might be other (i.e., nonlinear) forms of relationship which might have been appropriate. The particular equation used in the individual firm should be selected to fit the particular knowledge and data available.

If, as these results would indicate, there *may* exist the possibility of anticipating changes in the research budget through such variables as sales, profits, and the current budget, this information should not be ignored by the research director. By anticipating future business trends and considering current business conditions and current expenditures the research director may be able to anticipate future budgetary constraints *more precisely* than he is otherwise able to do.

Obviously, management reactions may change over time. Past philosophies do not necessarily continue throughout the future. Where, however, the data indicate that these philosophies *have persisted over time,* the research director can and should use this information to his and the firm's advantage in planning and selecting his research program.[6]

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[4] Firm 34 was excluded from this analysis because of peculiar computational difficulties involving the data.

[5] For an example of popular exposition on this point, see (1). The historical data presented by the author (in graphic form) seem to give tenuous support to the "invariance" argument.

[6] It might also be pointed out that the method of analysis used in this article is applicable to many additional business problems. For example, it could be used in an analysis of capital requirements, quantifying the previous relationship of inventory levels to business activity, planning manpower requirements in other company functions, the study of cost functions, and the analysis of the interrelationships between the various balance sheet items.

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To Queue or Not to Queue

(A One Act Play of Definition)

by **JAMES M. MOORE**

Department of Industrial Engineering, Stanford University

Cast: Charles Hall, *Vice President for Manufacturing of a large industrial plant.* Douglas Hoyt, *Methods Engineer, experienced but open-minded, not formally trained in mathematics and statistics.* Hugh Halstead, *Quality Control Manager, young, college graduate with M.S. in statistics from a prominent university, lectures at nearby Meadows College in evening.*

Scene: Corridor leading to parking lot of large industrial firm. Close to quitting time.

Prologue

(Enter right Charles and Douglas.)

Charles: Fletcher—you know the fellow from the sales department—came into my office the other day and informed me that he had lost five orders amounting to about ten thousand dollars in the last three weeks. It seems that all of these orders were lost because we couldn't get them out on time. This is a sizeable chunk of business, so I've spent a little time investigating. It turns out that each of the five orders got held up in the plating department. Have you been down there recently?

Douglas: No, I haven't.

Charles: Well, I made a special trip down there yesterday and found their inventory scattered for miles around. Not only was their department crammed full of inventory, but they've got materials awaiting plating stored in two other departments in addition. I don't know what the answer is, but I do know we have a bad bottleneck.

Douglas: It seems to me that the last time we added another plating tank was about fifteen years ago. I don't believe anything additional has been done in the department since that time. I'll look into it, if you like, and see what facts we can uncover.

Charles: That sounds good to me, Doug. Let me know how you make out. See you tomorrow.

Douglas: Goodnight. *(Both exit left towards parking lot.)*

ACT I

Scene: Industrial Engineering office, two weeks have passed.

(Continued on page 119)

INSTITUTE INTERESTS

Individuals, chapter officers, national officers and others are asked to become primary reporters and send in interesting highlights on local, national and international events. The principal criterion is that the item be current and of general interest. Material can best be handled if it is typed and double-spaced. Pictures to accompany these notices—or just good pictures with explanatory notes are welcomed. Send the material to Professor Wilson J. Bentley, School of Industrial Engineering and Management, Oklahoma State University, Stillwater, Oklahoma. If you forget this address, send it to the JOURNAL *Office in Atlanta, and I will get it.*—EDITOR.

AIIE GENERAL NEWS

The Board of Trustees met on December 10, 1960, January 21, 1961 and has scheduled a meeting for April 15, 1961. The principal topics discussed were plans for the National Convention in Detroit and the AIIE-ASEE Education and Industry Symposium (which precedes the Detroit Conference and Convention). Also considered was a proposal on Student Chapter Organization which promises to greatly aid that activity. More information on the student chapter plans will be printed at a later date.

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"The Effect of Foreign Competition on U. S. Industry," will be the topic of the Banquet Address at the Annual AIIE Conference and Convention, Thursday, May 11, 1961, in Detroit. The Speaker will be Mr. Robert Paxton, President, General Electric Company. Roger Crane, Conference General Chairman, announces the highlights of the evening: AIIE Honorary Membership and Fellow Certificates, Frank F. Groseclose Award, and ten Regional Winners in the Chapter Development Contest.

• • •

President Alex Rathe continues on his "sweep" across the country. He will make the following visits in March: Albuquerque, New Mexico Chapter on the 6th; Great Plains Chapter (Lubbock, Texas) on the 8th; Oklahoma City, Tulsa, Wichita and the Oklahoma State University Student Chapter on the 10th (in Stillwater, Oklahoma); Central Arkansas Chapter (Little Rock) on the 13th; Memphis, Tennessee Chapter on the 14th; Nashville, Tennessee Chapter on the 15th; and the Eastern Tennessee and Chattanooga Chapters in Knoxville on the 16th.

STUDENT CHAPTERS

The 1961 Southwest Area Student Conference was held in Houston, Texas on March 17-18 with the University of Houston Chapter as host. Papers were prepared by Industrial Engineering students in seven Southwestern Region universities who have student chapters. In conjunction with the Conference, Dr. Richard A. Dudek (Southwestern Area Student Chapter Chairman) held a Chapter Adviser's Conference.

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The Student Chapter of the American Institute of Industrial Engineers at North Carolina State College has won second place in the national annual student award competition.

A bronze plaque was awarded to the group at special award ceremonies held Thursday morning (January 26) in the Industrial Engineering student lounge. Dr. Alex Rathe, national president of the Institute, made the presentation.

The State College Industrial Engineering students were chosen from among more than 35 student branches in the nation for this award for their contributions during 1959-1960 to the welfare of the college, to activities benefiting the Industrial Engineering department, and to the advancement of the engineering profession.

"We are indeed very proud of our Industrial Engineering students at State College who have consistently placed high in the national competition over the last four years," said Dr. C. A. Anderson, Industrial Engineering department head. The State College chapter placed first in 1956-57 and third in 1957-58.

KEY FIGURES AT NORTH CAROLINA STATE COLLEGE AWARD CEREMONY—Standing left to right are Dr. C. A. Anderson, head of the department of Industrial Engineering; Paul Tosto of Raleigh, secretary of AIIE student branch; Richard Currie of Binghamton, New York, president of the student branch; Dr. Alex Rathe, national president of AIIE; C. E. Hunter, Industrial Engineering faculty member; and Dr. R. G. Carson, director of instruction for the college's School of Engineering.

PROFESSIONAL NEWS

The National Society of Professional Engineers has sent out questionnaires to all members of NSPE to obtain information concerning salaries and income of professional engineers in the United States. The survey is being made according to branch of engineering, area of working effort, type of company, geographical area, and grade of work performed. Results will be published in the organization's publication, *The American Engineer*.

ENGINEERS JOINT COUNCIL

Engineer's salary levels rose approximately 5% per year between 1958 and 1960 according to a survey conducted by the Engineering Manpower Commission of Engineers Joint Council. The overall median annual salary now stands at $9,600. The recent increase of 5% may be compared with an average annual increase of 6½% between the years 1953-1958. Seven years ago (1953), the first in this series of surveys found the median salary for engineers at $6500. These findings were made public by EMC in the fourth of

a series of surveys entitled, "Professional Income of Engineers—1960" which covers approximately 200,000 engineering graduates in industry, education and government.

The report which was announced by Dr. Sydney B. Ingram, newly elected Chairman of the Engineering Manpower Commission, also shows that engineers are a young group, with median age of about 32, based on a graduation average age of 22.

There is a marked difference between engineering salaries in industry, government and education, with the highest level in industry, followed by education and government. Of particular note is the 14.3% increase in the total professional income of engineering teachers between 1958 and 1960.

Earnings of engineers continued their upward trend, observed in the previous survey intervals 1953-56-58. The overall median (for all graduates) was $6,500 in 1953, $7,750 in 1956, $8,750 in 1958 (about 6.5% annually) and $9,600 in 1960 (up about 5% annually). The latter represents an increase from mid-1958 to mid-1960. For this same two-year span the Consumer Price Index rose 2.3% and the average Gross Weekly Earnings for Production (Manufacturing) climbed close to 8.9%.

Summary income data; median income as provided below:

ANNUAL EARNINGS (MEDIANS)

Years of Experience	*All*	*Industry*	*Education*	*Government*
1	$ 6725	$ 6775	$ 5375	$ 6275
5	8100	8200	7350	7175
10	9875	9975	9100	8750
15	11000	11250	10950	9075
28	12450	12575	12575	10650

INDUSTRIAL ENGINEERING PERSONALITIES

Dean Homer H. Grant was recently selected as the "Engineer of the Month" by the Los Angeles Council of Engineering Societies. Dean Grant is associate dean of the School of Engineering, University of Southern California, head of the Department of Industrial Engineering, acting head of the Department of Eletcrical Engineering, and is a well known consultant in the fields of industrial and management engineering and transportation.

As head of the Department of Industrial Engineering since 1954 (when the Department was first placed entirely under the School of Engineering), Dean Grant has worked effectively to improve the status, not only of the Department, but of Industrial Engineering in general. Passing the examinations for an amateur radio operator's license at the age of 13, and building sets which communicated half-way around the world by the age of 15, Dean Grant is one of those fortunate persons who knew at an early age what he wished to become. His interest lay in the management engineering portion of the engineering spectrum. To support himself through college, he became a Morse telegraph operator and later manager for Western Union.

After graduating from the University of Washington in 1933 as an engineer (with additional training in management, accounting and economics) he spent 10 years as an engineer in charge of research for the Washington and California public utility commissions and other government bodies. In 1943, he became assistant to the vice president and general manager and transportation engineer, for the Key System, Oakland.

After several years on the Executive Committee of the Key System, Dean Grant became a professor at USC, teaching engineering economy and administration, and has since been an Industrial Engineering, management, cost and operations consultant for many organizations. Dean Grant has been active in civic and professional organizations including AIIE, AIEE, ASEE, Los Angeles and Long Beach Chambers of Commerce. He has been a registered professional engineer for 24 years.

A member of Tau Beta Pi, the Society of the Sigma Xi, Phi Kappa Phi, Alpha Pi Mu (Hon.), Dean Grant is also a member of other professional and fraternal organizations. He is a 32nd degree Mason, and is listed in *Who's Who in America, Who's Who in Engineering* and *American Men of Science.*

Charles G. (Chuck) Howard, past president and organizer of the Charleston-Huntington Chapter No. 58, was chosen as Outstanding Industrial Engineer of Region III at the 1960 Regional Conference in Kingsport, Tennessee.

Chuck served as vice president of Region III and was a member of Board of Trustees, AIIE in 1959-1960. He is currently chairman of the AIIE national committee on Chapter Operation and Organization.

Among his outstanding achievements leading to the award was his work in the Charleston-Huntington chapter as a director where he sponsored committees on education, student chapters, professional relations and chapter development. The chapter attained "Award of Excellence" for three consecutive years leading the region in this respect.

Chuck served as a member of the Planning Committee for West Virginia Conference on "Utilization of Engineers and Scientists" under the auspices of the United States Presidents Committee. He was also a member of the Advisory Committee for the West Virginia University Industrial Engineering Conference which was co-sponsored by the Charleston-Huntington chapter.

Completing his military service in the Naval Air Corps in 1945, he received his B.S.I.E. degree from Pennsylvania State University in 1949. Since then he has been employed by the American Viscose Corporation as an Industrial Engineer at their Lewistown plant, as Staff Assistant to the Corporation Industrial Engineer at the Philadelphia home office and since 1953 has been chief Plant Industrial Engineer at the Nitro plant.

Chuck is very active in church and community affairs, being Assistant Superintendent of his Church School, a member of the Putnam County Board of Health, P.T.A., Viscose Management Club and National Management Association.

Married to the former Lin Rummel of Lewistown, Pennsylvania, they have two daughters, Karen (12) and Deborah (5) and reside at 9646 Maplewood Estates, Scott Depot, West Virginia.

PROGRESS IN ORGANIZATION

By Dave Overton, *Department Superintendent, Industrial Engineering, Union Carbide Nuclear Company*

The membership of the East Tennessee Chapter of the American Institute of Industrial Engineers believes that the way to progress is to be progressive. To meet the challenge of these changing times, the East Tennessee Chapter has completely realigned the functions of its officers. In this space age, the prime goal of the AIIE is to promote progress and professional development in Industrial Engineering. The East Tennesseeans believe that a sound organization is the best foundation on which to build for the future.

Acting under the challenge issued by Past President Johnson in March of 1960, the East Tennessee Chapter proceeded to study its own organization. Although the AIIE constitution designates

ORGANIZATION PLAN

President

Vice President-Controller	*Vice President-Public Relations*	*Vice President-Membership*	*Vice President-Programs*	*Vice President-National Relations*	*Vice President-Development*
Secretary	Newspaper, Radio and TV Announcements	New Members	Speakers	National Project Organization	Chapter Improvement
Treasury	Industrial Publications	Attendance	Arrangements for Speakers	National Meetings Participation	Organization Planning
Records	National AIIE Publications	Qualifications	Evaluation of Speakers	AIIE Activities Participation	Industrial Engineering Research Projects
Constitution	University Relations and Student Award	Regional Solicitation	Arrangements for Meeting and Meeting Place	Convention and/or Regional Meeting Preparation	Legislation
Financial Solicitation	High School Relations	New Industry	Selection of Subjects	National Affairs Report to Members	Long-Range Planning
Investments	Chapter Newsletter	Fellowship-Greeting	Social Activities	Job Opportunities	Chapter Development Award Project
Equipment	Student Chapter Relations	Identification Badges Visitors	Plant Visits	Delegates	Registration (Professional)
Fund-Raising Projects	Engineers' Week	Recent Graduates	Joint Meetings 1. Other Chapters 2. Other Organizations		
		Industrial Participation			

Executive Committee: Past President, President, Executive Vice President, Vice President (Concerned)

FIGURE 1

chapter officers, it also provides that the chapters have powers delegated to them to insure local control; therefore, the East Tennessee Chapter interpreted its right to experiment with a new and more progressive form of organization for the benefit of the entire AIIE. Until it was tried, a proposal to alter the constitution to allow a chapter control of its own organizational structure was premature.

Probably the first societies were protective in nature, involving groups who banded together, for common protection, against the hazards of nature and their more barbaric neighbors. However, among the early civilizations of Greece and Rome, the philosophers gathered to discuss matters of art, science, and philosophy, thus forming the basis for modern technical institutes. These informal groups gave way to a rather formal line organization which is still traditional with most societies, including the American Institute of Industrial Engineers. The formal line organization, as in the AIIE, normally consists of a president, a vice president, a secretary and treasurer, and similar officers, each with rather well-defined responsibilities. The traditional organization usually assuring a smoothly running group, has served us well, for many purposes, will continue to be the most effective method of organizing a club or a society.

The East Tennessee Chapter, nevertheless, believes that it has found a better way to serve its membership and to serve the Industrial Engineering profession. It has reorganized on a completely functional basis with a president and six vice presidents. The reorganization was the outcome of an exhaustive organizational study of the functions, duties, and responsibilities of all the officers and committeemen. The greater emphasis of the study, however, was placed on the purposes and the goals of the AIIE, the Chapter, the profession, and the membership. The vice presidents and a brief explanation of their functions are as follows: (See Figure 1.)

Vice President—Development

1. Industrial engineering research and development.
2. Professional development.
3. Chapter development.

Vice President—National Relations

1. Local participation in the affairs of the national organization.
2. Information and two-way communication among the national AIIE's organizational and technical programs.

Vice President—Programs

1. All arrangements for meetings.
2. Selection and evaluation of programs, subjects, and speakers.

Vice President—Membership

1. Recruitment and evaluation of the new members.
2. Industrial participation.
3. Attendance, fellowship, greeting, and identification of members and visitors.

Vice President—Public Relations

1. Newspapers, radio, TV, and industrial publications announcements.
2. College and secondary school relations, national magazines, and monthly newsletters.

Vice President—Controller

1. Secretary, treasurer, and records.
2. Investments, equipment, and fund-raising projects.
3. Constitutional matters.

Each vice president is a full-fledged officer of the Chapter and has both the responsibility and the authority to accomplish his functional assignments. The greater prestige of the vice president's office increases his personal interest in working for the institute and facilitates his accomplishments with associates and outsiders. With each vice president carrying a major share of the president's responsibilities, it is possible to conduct the meetings for their true purpose—professional progress. Many items of business are eliminated which ordinarily take up a great part of the meeting time. The president is free to accomplish his job of coordinating the various activities of the vice presidents into a sound organizational team; he also has the time to devote his energies to planning and development. The president can think ahead to the manner in which the local chapter can best serve its membership and promote the personal progress of members through activities in the institute.

The results of the experimental reorganization of the East Tennessee Chapter have been beyond expectations. Although relatively few Industrial Engineers are employed by most companies in the East Tennessee area (compared with other engineers and scientists), the most recent Industrial Engineering meetings have attracted outstanding attendance. The first meeting in the 1960-61 season brought an attendance of about 65 people, undoubtedly more than 100% of the Industrial Engineers in the area. The response of the membership has resulted in a greater participation of all members in the business of the Chapter and reactivated interest in the technical discourse at the meetings. It is much easier now to get active assistance from the members because of the improved opportunities for members to hold an office of distinction.

The outstanding success of this improved form of organization demands that the East Tennesseeans share their experiences with other chapters throughout the institute. Functionalization is not a novel idea, as major corporations have followed this structure for many years; neither is it unique in clubs or in social and professional societies. But, we of the East Tennessee Chapter do not believe that the merits of this system have been proclaimed adequately in the literature nor that its benefits have been seriously considered within the AIIE. Possibly the success of the experiment indicates a need for reconsideration of the constitutional specifications for officers. Perhaps the experience of one chapter may become a model for the others. Have you recently given any thought to the adequacy of the organizational plan of your chapter?

Progress can no longer be attained through the keeping of minutes and maintaining a formal routine. Improvements in organization, as well as in engineering, must be attained through attention to a wide variety of ever-changing affairs. Perhaps a streamlined functional organization may aid local chapters in their role of promoting progress in Industrial Engineering through the AIIE.

FORT WAYNE CHAPTER

The Fort Wayne Chapter has produced a 30-minute TV Program entitled, "More Time for Leisure and Profit". Civic players, acting in humorous pantomine (with the aid of narration) shows how to wash dishes, make beds, shave, and assemble articles in a factory. The film has been taped and is available at a small cost. Contact: Art Hill, 4438 Wilmette Street, Fort Wayne, Indiana.

TULSA CHAPTER

It is always news when a Fellow of AIIE shares his knowledge and philosophy with AIIE members. Professor H. G. Thuesen, of Oklahoma State University, drew one of this Chapter's largest crowds when he recently discussed the "Economics of the Educational Problem in General".

NORTH ALABAMA CHAPTER

ROBERT N. BRASWELL

Robert N. Braswell was elected president of the North Alabama Chapter of the American Institute of Industrial Engineers during a recent meeting at the Squirrel Hill Officers Club.

He succeeds E. L. Berrigan, who is employed by the Chemstrand Corporation in Decatur.

Other officers elected to serve with Braswell are Benjamin E. Bevill, vice president; William A. Meyer, corresponding secretary; James E. Bradford, recording secretary; Robert J. Masucci, treasurer; Donald H. Denholm, director for development and Peter Wright, director for organization and constitution.

Braswell, who holds a Master's degree in engineering from the University of Alabama, is also a member of the Engineering Faculty at the Huntsville Division of the University of Alabama.

He was elevated to president of the Huntsville Engineer Chapter from the post of vice president.

The local chapter has about 80 members from the North Alabama and Tennessee area. The election of 1961 officers took place at the regular monthly meeting.

LOUISVILLE CHAPTER

The Louisville Chapter voted to continue its grant of a $550 scholarship to assist "some deserving student enrolling in Speed Scientific School" for the school year 1961-62. This Chapter also has joint meetings with ASME and reports many benefits.

ROCHESTER CHAPTER

The feature event in the Rochester Chapter program for the 1960-1961 year will be the Spring Conference titled, "How Effective are Management Controls". The program for the conference this year has been expanded to two days (April 21 and 22, 1961) and will be held at the Rochester Chamber of Commerce. The conference will feature Dr. Alex Rathe, President of AIIE, as the luncheon speaker for the Friday session. He will talk on the "Competitive Challenge to Industrial Engineering". His talk will emphasize how the Industrial Engineer can help his company compete today with the ever increasing foreign and domestic competition.

Mr. Robert S. Rice, Managing Editor of the *Factory Management and Maintenance* magazine, will speak concerning the effectiveness of incentives. Messrs. Arthur J. Hutch, Stromberg-Carlson; Richard M. Wilson, Eastman Kodak; and Wallace Wilson, General Motors; will round out the balance of the Friday program.

The Saturday program will feature Mr. David N. Peterson of the Northrop Corporation who will give his presentation on PACE (Performance and Cost Evaluation). Mr. Robert E. Allen, past President of AIIE, from Shuron Optical, will be the luncheon speaker on Saturday and will talk on "Measuring Industrial Engineering Performance".

Dr. Lucien Brouha, duPont, will talk on his work in human physiology. The Saturday program will be completed by Messrs. Clinton B. Hutto, Haloid Zerox; Donald D. Thompson, Ernst and Ernst; Robert E. Allen, Shuron Optical. The topics for the final day will be technically oriented for the Industrial Engineer.

The chairman of the conference this year is Mr. R. Sparkes, Stromberg-Carlson, Rochester, New York. Further details in regard to this conference may be obtained from Mr. Sparkes.

RHODE ISLAND CHAPTER

The 110th Chapter, Rhode Island, had 21 officially recognized members as of February 1 and has had a very active life since its organization meeting on September 22. The Chapter officially received its charter in February from Henry Owades, Vice President of Region I.

GREATER ST. LOUIS CHAPTER

This chapter was honored in February with the presence of the First Lady of the Engineering World, Dr. Lillian M. Gilbreth. Dr. Gilbreth, now 82 years of age, is known as "The World's Greatest Woman Engineer". Throughout the United States and abroad, she is recognized as an eminent engineer, authoress, humanitarian, lecturer, and counsellor.

The Gilbreth story, "Cheaper by the Dozen" and "Bells on Their Toes", gave the entire world a needed lift. Many have received hope and inspiration through her philosophy that engineering principles can make the world a better place in which to live.

Many are the outstanding honors she has received: She is the first woman to win the Washington Award since the honor was first conferred upon Herbert Hoover in 1919. In 1944, Dr. Gilbreth and her late husband received the Gantt Medal from the American Society of Mechanical Engineers. In 1948, she was named "Woman of the Year" by the American Woman's Association; and in 1949, the National Institute of Social Sciences awarded her the Gold Medal for "distinguished service to humanity." Dr. Gilbreth holds 19 honorary degrees besides three other degrees acquired, and has served on the faculties of three universities.

INDUSTRIAL ENGINEERING AND INDUSTRIAL ENGINEERS IN INDUSTRY

LLOYD DEAMER AND JACK SWEERS are shown leafing through the United States Patent that was recently granted to the P. H. Gladfelter Company which bears their names as the inventors. The ten-page patent gives the company exclusive rights to a new assembly jig for making skids. These skids made from wood are used by the paper mill for a base which paper is stacked on for shipping to the customer. Mr. Deamer and Mr. Sweers struck on the idea for the jig while carrying on an Industrial Engineering project in the box shop to help streamline the skid making operations.

*** CALENDAR ***

*April 5: "The IE Approach to Cost Reduction Through Cost Controls." Speaker: Dr. Alex W. Rathe, National President AIIE, Professor of IE, NYU, College of Engineering.

April 6: Great Plains Chapter (Lubbock, Texas) Conference on Cost Reduction.

April 12-14: Purdue University's third Symposium on Information and Decision Processes, Purdue University, Purdue, Indiana.

*April 17: "Management Controls by Ratio Analysis." Speaker: Spencer A. Tucker, Partner, Martin and Tucker, Consultant IE's.

April 20-22: Annual Convention of the Illinois Society of Professional Engineers in Peoria, Illinois.

May 11-13: AIIE National Conference and Convention, Detroit, Michigan.

May 25-26: 19th National Meeting of the Operations Research Society of America, Sheraton-Blackstone Hotel, Chicago, Illinois.

May 22-26: 1961 American Society of Tool and Manufacturing Engineers National Convention, New York Coliseum.

June 5-16: Annual Work Design Intensive Course, Department of Industrial Engineering, Washington University, St. Louis, Missouri. Write to the Department for information.

June 5-16: Intensive Course in Operations Research and Systems Engineering, Homewood Campus of The Johns Hopkins University, Baltimore, Maryland.

June 5-15: Short Course on The Mathematical Techniques of Operations Research sponsored by Purdue University's Statistical Laboratory and Division of Adult Education, Purdue University, Lafayette, Indiana.

June 5-16: "Operations Research" course sponsored by the Case Institute of Technology, University Circle, Cleveland 6, Ohio.

June 11-16: Conference on "Mechanization Policy and Planning" sponsored by The Industrial Management Center, The Lake Placid Club, Essex County, N. Y.

June 11-16: Conference on "Capital Expenditure Analysis" sponsored by The Industrial Management Center, The Lake Placid Club, Essex County, N. Y.

June 13-16: Cornell University Industrial Engineering Seminars, Ithaca, New York. For additional information write: J. W. Gavett, Seminars Coordinator, Department of Industrial and Engineering Administration, Upson Hall, Cornell University, Ithaca, New York.

June 18-30: Conference on "Materials Handling" sponsored by The Industrial Management Center, The Lake Placid Club, Essex County, N. Y.

June 18-23: Conference on "Inventory Planning and Control" sponsored by The Industrial Management Center, The Lake Placid Club, Essex County, N. Y.

June 19-30: "Digital Control Systems Engineering" course sponsored by the Case Institute of Technology, University Circle, Cleveland 6, Ohio.

June 19-23: "Automatic Optimizing and Computer Control" seminar sponsored by the Case Institute of Technology, University Circle, Cleveland 6, Ohio.

July 10-28: "Process Control Theory" course sponsored by the Case Institute of Technology, University Circle, Cleveland 6, Ohio.

July 17-21: "Generalized Electrical Machine Theory" course sponsored by the Case Institute of Technology, University Circle, Cleveland 6, Ohio.

July 26-30: Annual Meeting of ASEE at the University of Kentucky, Lexington, Kentucky.

Sept. 12-15: Seminar for Manufacturing Engineers, Pennsylvania State University, University Park, Pa.

Sept. 17-22: Work Measurement Conference. Pennsylvania State University, University Park, Pa.

*AIIE Metropolitan New York Chapter Workship Subjects. All meetings held at National Cash Register Auditorium, 50 Rockefeller Plaza, New York City, at 7:00 P.M. Director of Workshops: Mitchell Fein.

I.E. OPPORTUNITIES

The I.E. Opportunities service is a functional committee activity of the AIIE. Information concerning employment opportunities is collected on a nationwide basis and is provided without charge to members upon request. The committee is composed of members from the Metropolitan New York chapter.

SERVICES PROVIDED

Current job openings are published in condensed form in each issue. In addition, a monthly I. E. Opportunities Bulletin is supplied to over one hundred chapters located throughout the U.S.

Each job opening is assigned a **"P"** number for identification. The name and address of the person to contact for additional information concerning a specific job opening is sent to members on request.

EMPLOYERS

Employers having openings for qualified Industrial Engineers are invited to list them. Government agencies and educational institutions as well as business and industry are urged to take advantage of this free service.

To list your job openings with the Opportunities Service, send all or part of the following information with the name of your contact man to the address below: Type of industry, location, job classifications, minimum educational and experience qualifications, and salary range.

MEMBERS SEEKING JOB OPPORTUNITIES

The following list shows job openings available just prior to press time. If you would like more information about one or more of the positions listed, mail the **"P"** numbers with your name and address to the Opportunities Service at the address below. The Service will advise you by return mail of the name and address of the person to contact for further information, or advise you if the position is no longer available. Your name will not be forwarded to the company with the job opening.

For more current listings, contact your local Chapter Secretary or Opportunities Chairman for the latest monthly Bulletin.

ADDRESS OF THE SERVICE

I. E. Opportunities Service
American Institute of Industrial Engineers
32 West Fortieth Street
New York 18, New York

Position number	Industry, location		Travel?	Job classification number (See key)	Salary range $1,000	Qualifications required		
						Years of exp.	Age range	Remarks
41	Consulting	Ohio	×	10, 21, 31		5-7		
167	Weapons Systems	Wash. D.C.		50				Ph.D.
213	Air Force and Missiles	Calif.		12, 15, 32, 42, 43, 44, 53	5.3-7.5	2+	21-	B.S. in I.E.
273	Air Force	Utah		11, 13, 18, 42, 43, 44, 53	6.3- 7.5	2-		I.E. Degree
423	Air Force	Ohio		Broad	8.8			I.E. Degree
424	Air Force	Ohio		Broad	4.5- 7.5			I.E. Degree
449	Electronics	Mass.		30, 50, 70	6.0- 8.0	1-5		
464	Consulting	N.J.	×	10, 20, 32-34, 42, 43, 54, 71-73, 92	8.0-12.0	5-	30-36	I.E. Degree
465	Consulting	Mass.	×	Senior Engineer	12.0-15.0	10-15	32-50	I.E. Degree or Equiv.
470	Mining & Smelt.	N.M.		11, 13, 26, 36, 42, 45	5.0-7.0		-45	I.E. Degree Preferred
472	Plastic and Wood Prod.	Va.		11	8.0- 8.5	1-2	-30	MTM Experience(Woodwkg.)
493	Plumbing Supplies	Ohio		11, 13, 18	7.5- 9.0	7-	30-35	I.E. Degree
499	Electronic Equip.	N.Y.		10, 36	Open	3-		I.E. Degree or Equiv.
503	Electronics	D.C.		30	9.0-11.7	5-		I.E. Degree
514	Air Force	Ohio	25%	12, 17, 18	8.8-10.0	4+		B.S.I.E. or M.S.I.E.
515	Air Force	Ohio	25%	40	8.8-10.0	4+		B.S.I.E. or M.S.I.E.
516	Air Force	Ohio	25%	32, 37	8.8-10.0	4+		B.S.I.E. or M.S.I.E.
517	Air Force	Ohio	25%	10, 13, 16	8.8-10.0	4+		B.S.I.E. or M.S.I.E.
518	Air Force	Ohio	25%	Broad I.E.	8.8-10.0	4+		B.S.I.E. or M.S.I.E.
519	Automotive Parts	Mich.		10, 11, 13, 19, 26, 36, 38, 42	6.0- 9.0	7-20	30-45	College Degree
524	Utilities	D.C.		10, 13, 17, 37	6.0- 7.2	1-3	25-	I.E. Degree
534	Glass Conditioners	N.Y.	25%	10, 11, 22, 36, 43,	7.5-10.0	3-5	-40	I.E. or M.E. Degree
538	Papermaking	Pa.		50, 51, 52, 53, 54,55	Open	2-5	25-35	M.S.I.E.
539	U. S. Army	Ill.	×	37, 52, 53, 54	8.8- 9.5	3-		B.S. Degree
542	Electronics	N.Y.		19, 42, 43	5.2- 8.5	0-3		B.S.—I.E., I.M., or M.E.
543	Air Force (Maint.)	Pa.		11, 13, 18, 44, 53, 91	7.5	4-	25-40	I.E. Degree
545	Consulting	Pa.	×	10, 20, 30, 40, 50, 70, 90	8.0-10.0	5-	28-40	M.E. or I.E.
553	Sugar Refining	Md., La.		11, 36, 38, 43	6.2-9.0	0-5		I.E. Degree
556	Office Machy.	Mich.		30	9.6-	3-5		Exp. in Quality Control
566	Education	Mo.		10, 30, 40, 50	Open			College Degree
570	Transportation*			10, 30, 42, 43, 47	7.0- 8.4	4-	20-	I.E. Degree
571	Transportation*			10, 30, 42, 43, 47	6.0-	None	20-	I.E. Degree
572	Mgmt. Consultant	U.S.A. & Europe	×	10, 11, 13-18, 21, 22, 91 or 92	Open	5-	30-40	MTM Experience
585	Garment Mfg.	N.J.		10	5.2- 5.7	0-2		I.E. Degree
587	Naval Avionics	Ind.		11, 30, 40, 70	6.4- 7.5	2-5		I.E. Degree
588	Printing	Ohio		10, 20, 31, 42, 43	Open	2-5	-30	B.S.I.E. or M.S.I.E.
593	Metal Working	Mich.		10, 11, 13, 20, 39, 42	10.0-	10-		Engineering Degree
594	Chemical Mfg.	Tex.		Methods Analyses	8.0	2-6	-35	B.S.I.E. or B.S.M.E.
595	Plastics	Ill.		11, 42-46	7.2- 8.4	5-		B.S.M.E. or B.S.I.E.
601	Wood and Plastics	Va.		21	7.5- 8.0	2-3	25-35	B.S. Degree
603	Training	Mich.		30—in Metal Cutting	7.0-	3-5	25-	B.S., M.S., Ph.D. I.E., M.E.
604	Training	Mich.		30—in Plastics	7.0-	3-5	25-	Same as above
607	Elect. Controls	Mass.		30,32,39	10.0-12.0	8-10	-40	I.E. or M.E. Degree
609	Research & Devel.	Md.		30, 40, 42		8-		B.S.I.E.
610	Research & Devel.	Md.		30		5-		B.S.I.E.
611	Research & Devel.	Md.		30		3-		B.S.I.E.
615	Heat Trans. Equip. Mfg.	Wis.		11, 19, 32, 38	6.6-	3-	-45	B.S.I.E. Pref.
620	Food Machy. Mfg.	Iowa		36, 42, 43	6.0- 8.0	5-		M.E. Deg. or 2-3 Yrs. Col.
621	Boats	Mich.		30, 40	6.0- 8.4			
622	Casing Testers	Texas		30, 71		3-5	-35	B.S.I.E.
623	Semiconductors	Mass.		11, 13, 16, 18, 42	8.0-11.0	3-5		
624	Navy	D.C.		44, 49, 54, 70	4.5- 7.5		Open	
626	Mining, Milling, Smelting	Utah		13, 21, 26	7.0-10.6	3-8	25-35	Engineering Degree
630	Textile & Paper Prod.	Tenn.		10, 11, 13-15, 18, 21, 22, 26, 36	6.0- 7.5	2-3		I.E. Degree or Equiv.
631	Air Force (Maint.)	Pa.		10, 11, 13-15, 18, 30-34, 39-47, 90	7.5	3	20-	B.S.I.E.
632	Air Force (Maint.)	Pa.		10, 11, 13-16, 18, 30-34, 39-47	7.5	3	20-	B.S.I.E.
633	Air Force (Maint.)	Pa.		10, 11, 13-16, 18, 30-34, 39-47	6.2	2	20-	B.S.I.E.
634	Air Force (Maint.)	Pa.		10, 11, 13-16, 18, 30-34, 39-47	4.9	0	20-	B.S.I.E.
635	Air Force (Maint.)	Pa.		10, 11, 13-16, 18, 30-34, 39-47	5.8	1	20-	B.S.I.E.
636	Air Force (Maint.)	Pa.		10, 11, 13-16, 18, 30-34, 39-47	6.2	2	20-	B.S.I.E.
639	Education	N.Y.		10, 30, 40, 50, 60	9.0-12.0	5-15		Ph.D. in I.E.
640	Athletic Equip.	Ohio		11, 13, 16, 19, 26, 32-34, 42, 44	8.4-	5-6	30-40	MTM required
641	Athletic Equip.	Ohio		11, 13, 16, 32, 42	6.5-	3-4	25-45	MTM required
642	Rubber (Ind. Prod.)	Mass.		10, 11, 13-15, 20-22, 32, 36, 38, 42, 43	Open	3-7	25-40	College Graduate
643	Pharmaceutical	Ind.		10, 11, 13-15, 18, 19, 42, 43, 53	6.0- 6.5	0-3		I.E. or M.E.

* Openings in New York City, Detroit, Mich., Syracuse, N.Y., Indianapolis, Ind., and Cleveland, Ohio.

Position number	Industry, location		Travel?	Job classification number (See key)	Salary range $1,000	Qualifications required		
						Years of exp.	Age range	Remarks
645	Management Cons.	Minn.	40%	13, 31, 37, 43, 53, 55, 71, 72, 91	11.0–	5–	29–45	Engineering Degree
647	Printing	Eastern U.S.		50	Open		30–45	B.S. in I.E. or Equiv.
650	Chemical Proc.	W. Va.		15, 17, 48, 91	6.0– 7.2	0–2		B.S.I.E.
651	Propane Equip.	Ill.		10	5.4– 6.0	3–		Degree not required
653	Research Lab.	Md.		30, 40 (Principal Engineer)		3–		B.S.I.E.
654	Research Lab.	Md.		30, 43 (Methods Analyst)		3–		B.S.I.E. or I.M.
655	Film and Paper	N.C.		10, 20, 30, 42, 43, 49, 53, 70, 73, 81	Open	0–5	21–30	I.E. Degree
656	Forgings, Stampings, etc.	Northeast		(Division Manager)	15.0–18.0	8–10	35–	I.E. Degree
658	Food Proc.	Minn.	Ltd.	10, 20, 30, 40, 81	5.7– 6.1	0–2	Open	I.E. or I.M. Degree
660	Consulting	N.Y.	X	10, 21, 36, 38, 91, 92	12.0–20.0	8–	35–45	M.E. or I.E. Degree
672	Electronic	N.Y.		10, 30, 42, 43	–12.0	5–		M.S. or B.S. in I.E.
673	Electronic	N.Y.		11, 13, 36	–12.0	2–		Electronic Exp.
675	Power Farm Machinery	Iowa		General	Open	2–5	30–45	I.E. Degree
676	Clay Products	Tex.	Ltd	12, 21, 36, 42, 43	5.8– 6.6	5–	28–35	I.E. Degree or Equiv.
679	Education	Conn.		Asst./Associate Professor				Doctor's Degree in I.E.
680	Pulp & Paper	Maine, Pa.		11, 31, 37, 43, 49, 91	6.0–	Open		B.S.I.E.
686	Lamp Mfg.	N.J.		10, 11, 14, 15, 20–23, 90, 92, 95	9.0–12.0		35–	I.E. Degree
687	Wood Furniture	Mo.		10, 11, 13, 21, 22, 36, 39, 47	7.0– 9.0	5	30–40	I.E. or M.E. Degree
688	Metal	Ind.		10, 13, 15, 30, 36, 40	Open	8–10	30–35	B.S.in Ind. Engineering
689	Corrugated Containers	Midwest		10–16, 21, 26, 60	6.0– 8.0	2–5	25–35	I.E. or M.E. Degree
690	Optical	N.Y.		10, 13, 19, 20, 36, 38, 42	9.0–12.0		35–45	I.E., M.E., and E.E. Degree
691	Navy	Hawaii		10, 20, 30, 40, 60, 70	7.5–	4		I.E. or Equiv.
693	Education	Ohio		31, 37, 38, 50	Open		30–50	Master's Degree Pref.
695	Electronics	Calif.		30, 32, 38, 39, 44	7.2	3		
703	Tobacco Mfg.	W.Va.		11, 18, 42, 43	Open	1–3	23–28	I.E. Degree, must have satisf. Milit. Serv. Requirement
704	Government Agency	N.Y.		10–19, 70–72	6.4– 7.5	3–		B.S.I.E.
705	Synthetic Fibers	N.C.		10, 11, 13–20, 32–36, 42, 43, 50, 53, 81	Open	0–5		I.E. Degree
706	Tire & Rubber	Ohio		10–20, 36, 38, 70	8.0	3–4	–30	I.E. Degree
707	Education & Research	R.I.		10–20, 30, 40, 60	6.4– 8.5			I.E. Degree
708	Mining, Milling, Smelt.	Nev.		10, 11, 13, 14, 21	6.5–10.5	2–	–45	I.E. Degree or Equiv.
709	Textile	N.C./S.C.		28 for S.C. 10, 11, 18, 21, 26 (For N.C.)	7.0–	3–	–25	I.E. Degree
710	Food Processing	Minn.		50, 51, 52, 53	8.0–10.0	2–	25–35	M.S. in I.E. or Applied Math.
712	Motor Mfg.	Ark.		10–20, 30, 40	6.0– 7.0	0–		I.E. Degree
714	Navigation	Calif.		10, 36, 37, 38, 42, 43, 50, 53, 91	8.0–14.0	3–12	24–40	B.S.I.E., M.S.I.E. or Equiv.
715	Education	Mich.	Min.		7.0–	3–5		B.S., M.S., Ph.D. I.E. or M.E. with desire to teach
717	Chemical	Mass.		19, 30–33	7.0– 9.0		Open	I.E. with Mechanical Aeronautical Eng. Background
718	Rubber	Md.		10, 11, 15, 19, 21, 26, 30	Open			I.E. Degree or Equiv.
720	Textile	Ga.		10–15, 18, 21, 22, 23, 34	6.0– 7.0	0–3	30–	I.E. Degree
721	Paper	Va.		10–18, 30–36, 41–47, 52, 53, 70, 81	6.4–	0–3	–30	I.E. Degree
722	Forest Products	Ark.		11, 30, 48	Open	3–4		I.E. Degree and or Adv. Degree
723	Forest Products	Ark.		10, 11, 13	Open	3–4		I.E. Degree and or Adv. Degree
725	Association	N.Y.		Program Director Mfg.	10.0–12.0		30–35	Broad Experience
726	Bedding	Minn.		11, 18, 30, 32, 35, 36, 40, 92	15.0–19.0	5–10	35–45	I.E. Degree
727	Grain Milling	Iowa		10, 11	Open			Prefer Grain Milling Exp.
728	Textile	N.C., Va.		10, 11, 14, 22, 28, 91	6.0– 8.0	2–6	21–35	College Graduate
729	Education	Ohio		10, 19, 30, 32, 39, 44, 47	7.0+	3–5	–50	
730	Sugar Refining	Pa.		10, 19, 36, 43	–6.6	0–1		Jr. I.E. Degree
731	Sugar Refining	Pa.		10, 19, 36, 43	–8.1	3		
732	Electronics	Md.		37—Section Chief		6–8		Design & Quality Control
733	Electronics	Md.		30—Section Chief		10		Experience in Prod. Tech.
734	Textiles	Miss.		91, 92	7.0+	2–5	–35	I.E. Degree or Equiv.
735	Air Force	Pa.	Occ.	10, 11, 14, 15, 13, 16, 18, 30–34, 39–47	7.5	3	20–	B.S. in Engineering
736	Air Force	Pa.	Occ.	10, 11, 13, 14, 15, 16, 18, 30–34, 39–47	6.4	2	20–	B.S. in Engineering
737	Mfg. Heavy Ind. Equip.	Wis.		19, 30, 32, 34, 36, 44, 47, 53, 90	10.0–15.0	10–		Engineering Degree
738	Chemical Mfg.	Alberta, Canada		11, 13, 15, 30, 36, 40, 53, 70	Open	0–10	–35	I.E. Degree
739	Education	Conn.		Assist. or Assoc. Professor				Doctor's Degree in I.E.
740	Semiconductor	Fla.		70, 18, 12, 34, 50, 36	–7.5			B.S.M.E. or I.E. Pref. Rec. Graduate top ¼ Class.
741	Instrumentation	Texas		70, 80	7.2– 9.6	3–5	–35	B.S. in I.E. or M.E.
742	Chemical	N.M.		Mechanical Inspector	8.0	3	–35	B.S. in I.E.
743	Chemical	N.M.		Mining	9.6	5	–35	B.S. in I.E.
744	Chemical	N.M.		11	7.5	5	–40	B.S. in I.E.
745	Chemical	Southwest		Jr. I.E.	7.2	2	–35	B.S.I.E.
746	Food	Texas		11, 15	6.0– 7.2	2–	–35	B.S.
747	Chemical	Texas		11	8.0– 8.5	2–	–35	B.S.I.E. or M.E.
748	Food Processing	Minn.	Lim.	70, 71	6.0– 7.3	2–4	Open	I.E. or I.M.
749	Mgt. Consult.	Middle-East Countries		13, 26, 37, 42, 50, 61, 63, 71, 72	Open	5–10	30–35	I.E. Degree, Some Petroleum Exp.
750	Mfg. Athletic Equip.	Ohio	15%	11, 14, 21, 30, 32, 40, 47, 70	6.0– 9.0	2–10	25–35	B.S. Engineering
751	Soft Goods	Midwest	Occ.	10, 30, 37, 95	8.0–15.0	2–10	–48	Open Ed. Exp. in Soft Goods
752	Steel Foundry	Pa.		10, 11, 13, 14, 15, 18, 21	6.0– 7.0	0–5		I.E. Degree
753	Printing	Ohio		31, 33, 35, 19	Open	2–	–35	
754	Railroad-Intrastate	Minn.		19, 21, 23, 46, 31, 27, 90	7.2–12.0	0–		B.S.I.E. or Other Degree with I.E. Exp.
755	Electro. Mech. Mfg.	Ill.		11, 15, 22, 36, 38, 39, 40, 92	10.0–15.0	10–15		B.S.I.E. or M.E. 10 Yrs. Supervisory Exp.
756	Electronics	Md.		Technical Sale	15.0–20.0			Background in Sales or as Proj. Leader
757	Electronic Mfg.	N.Y.	Mod.	11, 36, 41, 49, 50	8.0–10.0	5–		I.E. Degree or Equiv.
758	Electronic Mfg.	N.Y.	Mod.	11, 36, 41, 49, 50	10.0–12.0	10–		I.E. Degree or Equiv.
759	Precision Metals	Calif.		10–18, 30, 36, 38, 42, 49, 71	8.0– 8.5	2–3	25–35	I.E., M.E. or Equiv.
760	Electronic Equip.	N.Y.		11, 13, 16, 18, 32, 34, 39, 42, 43, 63	6.5– 8.5	2–5 Pref. Elec.	21–40	I.E. Degree or Equiv.
761	Electronic Equip.	N.Y.		11, 15, 18, 38, 42, 53, 70	6.5– 8.5	2–5 Pref. Elec.	21–40	I.E. Degree or Equiv.
762	Electro-Mech.	N.Y.		Asst. to President	10.0–13.0 and Prof. Shar.	5– Pref. Mfg.		College Degree
763	Pulp and Paper	Fla.		11, 13, 18, 42, 36, 43	8.0– 9.6	6–10		I.E. Degree or Equiv.
764	Airline	Ill. Colo. Calif.	15%	11–13, 17, 42, 43, 49–52	6.0–10.0	1–5	–40	I.E. Degree of Equiv.
765	Plastics	Va.		Methods Engineer	– 8.1	2–5	28–45	I.E. Degree or Equiv.
766	Wood	Va.		10	– 7.8	4–6	30–45	I.E. Degree or Equiv.
767	Heavy Mach. Shipbuild.	Va.		10, 15, 18, 19, 21, 36	6.0– 8.5	0–5	21–35	I.E. Degree of Equiv.
768	Wood Plastics	Va.		10, 21	7.5– 8.5	2–5	25–35	College Degr. or Equiv.

Position number	Industry, location		Travel?	Job classification number (See key)	Salary range $1,000	Qualifications required		
						Years of exp.	Age range	Remarks
769	Wood, Plastics	Va.		Junior Project Engineer	5.0- 5.5		-30	I.E. Degree or M.E.
770	Wire	Wis.		21, 26, 28	10.0	5-	30-35	Several Yrs. as Chief I.E. Pref.
771	Hospital	Ill.		Broad	8.4- 9.6	2-3		B.S.I.E. or M.S.I.E.
772	Chem. Mfg.	Tex. La.		10, 11, 13, 14, 18, 36, 38	6.0- 9.6	0-5	21-26	B.S., M.S., I.E., M.E., or Equiv.
773	Education	Kan.		10, 20, 30, 40, 50, 60, 70, 80, 90 (not all)	7.5- 8.5			Teaching & Ind. Exp., Opport. for Con.
774	Pulp & Paper	Calif.		11, 30, 36, 41, 42, 43, 44, 45, 46, 47, 52, 53, 71, 81	Open	2+	Open	B.S., I.E., or M.E., M.S. or M.B.A. Pref.
775	Rubber Sundries	N.Y.		18, 13, 21, 36	7.2	1-3		I.E. Degree
776	Varied	Europe or S.A.	Reloc.	49, 54, 70, 71, 72, 73	Open	5-		
777	Varied	Europe or S.A.		11, 13, 21, 31, 37, 45	Open	5-		
778	Textile	Europe or S.A.		11, 13, 21, 31, 37, 45	Open	5-		
779	Knitting	Europe or S.A.		49, 54, 70, 71, 72, 73	Open	5-		
780	Mil-Elect.	Md.		Chief, Production Engineer	Open	10-		B.S.I.E. or M.E.
781	Oil	Middle East		10, 30, 40, 70	13.0-17.0	7	30-40	College Degree
782	Air Force	Ala.		12-19, 31-38, 49-54, 71, 93	12, 21-13.51	5-6		B.S.I.E. or M.S.I.E.
783	Air Force	Ala.		11-19, 30, 47, 49-54, 71, 93	12.21-13.51	5-6		B.S.I.E. or M.S.I.E.
784	Air Force	Ala.		11-19, 30-38, 43-47, 49-55, 81, 92	10.635-11.935	4-5		B.S.I.E. or M.S.I.E.
785	Air Force	Ala.		12-19, 31-38, 49-57, 71, 92	10.635-11.935	4-5		B.S.I.E. or M.S.I.E.
786	Air Force	Ala.		11-19, 30-47, 49-54, 91	7.56-10.225	3-4		B.S.I.E. or M.S.I.E.
787	Fitting, Foundry	Ohio		10, 13, 18, 36, 42, 34, 49	10.6-	3-		I.E., Some Supervision
788	Metal Products	Va.		21, 10, 16, 15, 19, 36, 11	6.0- 7.5	3-	28-	Deg. or Equiv. Wage Incent Exp.
789	Consulting	Pa.	Yes.	10-18, 20-28, 30-36, 90	12.0-16.0	10	35-	I.E. or Equiv.
790	Education	Ohio		10, 30, 50	Open		Pref. Rec. Gradu.	M.S. in I.E. or M.E. Strong in I.E.
791	Education	Fla.		11, 28, 30, 31, 42, 47, 70, 71	Open	4-	30-45	M.S. or Ph.D. in I.E.
792	Mgt. Consult.	U.S.A. & Europe	Yes.	11, 13, 15, 21, 22	Open	5-7	35-	MTM. Exper. Foreign Lang.
793	Mgt. Consult.	U.S.A.		11, 13, 15, 21, 22	Open	5-7	35-	MTM. Exper.
794	Education	Va.		30, 39, 42, 43, 44, 47	5.2- 7.0	3-		M.S.I.E. Min. Pref. Ph.d.
795	Elect.	N.J.		10, 30, 42, 36	6.5- 8.7	0-3		I.E. Degree
796	Chem.	N.J.		Jr. I.E.	6.0			I.E. Degree & Time Study Exp. Pref.
797	Chem.	N.J.	Some	92	15.0+	Heavy		I.E. Degree & Multi-Plant Paper Exp.
798	Chem.	N.J.		92	10.0+		Open	I.E. Degree & Heavy Time Study

Key to Job Classifications

No.	Job Classification
10	Motion and Time Study
11	Methods Improvement (Production)
12	Methods Improvement (Office)
13	Work Measurement and Perf. Stds.
14	Stop Watch Time Study
15	Std. Time Data Dev. & Applic.
16	Predeter. Elemental Time Stds.
18	Work Sampling
19	Estimating and Costing
20	Wage Payment
21	Incentive Plans
22	For Production Workers
23	For Non-Prod. Workers
24	For Supervisory Personnel
26	Job Evaluation
28	Wage Administration
30	Production Engineering
31	Production Control
32	Process Planning and Routing
33	Scheduling and Loading
34	Flow Process Charting
35	Inventory Control
36	Cost Anal. & Reduction
37	Statistical Quality Control
38	Budgetary Control, Standard Costs
39	Tool and Gage Design and Control
40	Plant Engineering
41	Plant Location & Expansion
42	Plant Layout
43	Material Handling
44	Machinery & Equipment
45	Specif., Select. & Eval.
46	Replacement
47	Automation
48	Plant Maintenance
49	Cap. Budget. Facil. Plan
50	Operations Research
51	System & Simulation with "Models"
52	Mathematical Analysis
53	Engr. Economy Studies
54	Auto. Data Proc. with Computers
55	Market Research & Forecasting
60	Industrial Relations
61	Personnel Administration
62	Personnel Testing
63	Personnel Training
64	Industrial Psychology
65	Labor Relations
66	Safety Engineering
67	Suggestion Systems
70	Systems and Procedures
71	Admin. & Operating Procedures
72	Organization Charts and Manuals
73	Records Admin. & Form Control
80	Product Design
81	Packaging
90	Management and Supervision
91	Industrial Engineering Supr.
92	Chief I. E. or Equiv.
93	Plant Engineer
94	Production Supervisor
95	Plant Mgr., Fact. Mgr., Works Mgr.
96	General Manager

Hugh: You look mighty troubled, Doug. What seems to be your problem?

Douglas: Well, a couple of weeks ago, Charlie asked me to look into the inventory mess out in the plating department. There's a real bottleneck out there, but I'm not sure which way to turn. I've noticed that there have been quite a few articles in the Industrial Engineering Journal recently on this thing called queueing. It occurred to me that there might be merit in looking at the plating department in terms of a queueing model. At any rate I've been digging into some of my back issues. I've even taken a couple of trips to the plant library this week to look up references in the Operations Research Journal, but I'm snowed by the mathematics and the amount of material on queueing. Aren't you doing a little work in Operations Research in your evening course over at Meadows College?

Hugh: As a matter of fact I gave a lecture a couple of weeks ago attempting to introduce queueing theory to the group. I can certainly understand your confusion, because there is a tremendous amount of literature written during the last decade. Actually quite a number of queueing models have been developed, and I suspect that you are wondering if one of them might logically be applied to the plating department. Perhaps you might be interested in a little chart that I prepared for my evening class. It's a graphical summary of the queueing models that have been developed to date. *(Hugh goes to his desk and removes a rolled up chart, which is shown in Figure 1, and spreads it out on Douglas's desk.)*

Douglas: Looks like an organization chart.

Hugh: It was the only way I could think of to summarize briefly the interrelationships of queueing theory. Notice the five blocks in the top row of the chart containing the terms customer population, number of channels, queue discipline, arrival distribution and service distribution. In order to define a given queueing model information must be obtained about each of these five items. On the chart the currently developed models are specified by following down from each of the five items until a dead-end branch is reached.

Douglas: Let's start at the left side of the chart and work across. I presume the term customer population means the persons or items desiring service.

Hugh: That's correct. They are sometimes called "arrivals" in the literature. Notice that there are two branches growing out of the "Customer Population" block. These represent two distinct classes of models based on the size of the customer population. If the number of customers is very large and the demand correspondingly small, it is convenient to assume that the customer population is infinite. This assumption considerably simplifies the computational effort, however there are many queueing problems where this assumption cannot reasonably be made, hence the finite category.

Douglas: Can you give me a couple of examples to differentiate between the two classes?

Hugh: The number of telephone subscribers for a given exchange tends to be quite large while the demand for the circuits, perhaps measured in average number of calls per idle customer per unit time, is rather small. It's safe to assume an infinite customer population here. However if the 8 trucks in our delivery fleet are the customers waiting to load up at our shipping room dock, then the finite model must be used. Although most of the theoretical work has been done in the infinite customer population case, there is a convenient set of tables (10) for the finite case. If you read through the Shelton (12) article in the *Journal*, you might have noted that all his graphs are for infinite customer populations.

Douglas: No, I didn't pick that out. *(Pause while looking over chart)* This next category—Number of Channels—seems clear cut. The single channel is for one service facility, for example, only one toll collector on the bridge so that all customers must wait for him to collect from the customers ahead. Multiple channels would be the case if there were two or more toll collectors on the bridge. However I'm puzzled about the infinite number of service channels. Where would you encounter this situation?

Hugh: Off hand I can't think of any applied problem that would fit into this category, however, I've included it in the chart because mathematically it is probably the easiest to handle of all queueing models. It was developed some time ago by Feller (4). Notice that the finite service channels may be taken in series or parallel. The vast majority of queueing problems involve parallel channels. For example, if five toll booths are open, the customer can obtain the same service from any one of the booths, i.e., he pays at only one of them. However, a limited amount of work has been done with service channels in series where the customer must queue up to go through Channel 1 and then proceed to queue up to go through Channel 2 which provides another type of service.

Douglas: The category "Queue Discipline" seems to be rather involved.

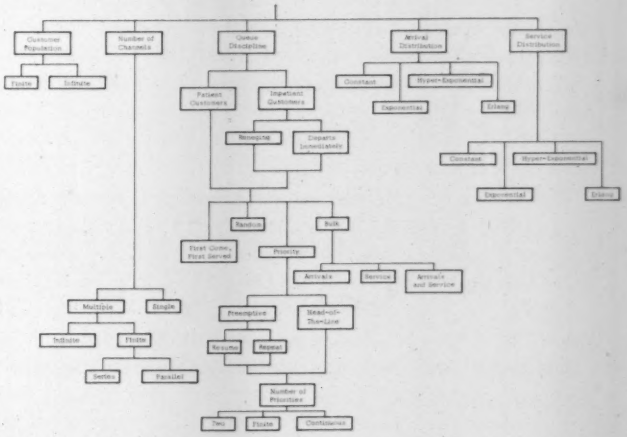

FIGURE 1

Hugh: Yes, the queue discipline is the order in which the customers are served, and there are a number of variations.

Douglas: Does your general rule of following down the branches on your chart until a dead-end is reached still apply here?

Hugh: It certainly does, but notice that under queue discipline you must make a few "either-or" choices. For example, all customers are either "patient" or "impatient." They must be one or the other. For example, if the customer is a machine tool awaiting the service man, it will wait patiently in the queue indefinitely, but human customers are apt to be impatient. If there are too many people ahead at the barber shop, the customer is apt to let the wife cut his hair rather than wait.

Douglas: There appear to be two types of impatient cutomers. Can you clarify them?

Hugh: Some impatient customers will leave immediately if they see a queue, that is, they will never join the queue. Others will join the queue, but will become restless if they are not serviced and at some time during their stay in the queue will depart. The latter is a reneging customer. Barrer (1) has developed a model with impatient customers. After determining the customer's patience, follow down the chart to the four most common types of queue disciplines, namely, first come-first served (FC, FS); random; priority and bulk.

Douglas: First come-first served obviously indicates that the first customer to arrive at the toll booth, for example, will be the first one to be serviced, that is, pay his toll. Where would the random queue discipline be used?

Hugh: Suppose you are a telephone switchboard operator. One of your circuits becomes available for a new call. The customers, people attempting to place a call, are waiting for the line. You don't know which of these waiting customers tried to place his call first. How would you choose among the waiting customers?

Douglas: I guess that I'd have to just pick one at random. *(Pause)* I can imagine a number of industrial applications of this discipline particularly where the customers are things, not people. *(Pause)* The priority discipline must be where one type of customer has preference over another type of customer. Let's see, the doctor's office would be an example where he takes all children first and asks the adult patients to wait.

Hugh: Miller (7) summarizes much of the work done on priority queue discipline models. The bulk discipline is somewhat new, but is useful in industrial problems. Here the customers arrive or are served in a group. For example, the passengers debarking from an airplane will arrive in a group. This would be bulk arrivals. On the other hand some problems involve bulk service, like the elevator where passengers may arrive individually but are serviced in a group. Downton (3) has done work on this case. Sometimes both the arrivals and service use the bulk queue discipline. Miller (8) describes this situation. However in this event it may be simpler to redefine the customer unit.

Douglas: Going back to the priority discipline, what is meant by a preemptive priority?

Hugh: Let's look first at the "head-of-the-line" priority, which merely means that when a higher priority customer arrives, he goes to the front of the waiting line. A number of adults are waiting in the doctor's office and a child arrives. With "head-of-the-list" discipline the child is the next to see the doctor. Cobham (2) introduced the "head-of-the-line" priority model. Suppose that the police bring in a patient from an automobile accident who needs immediate medical attention. As a result the doctor asks the patient in service to return to the waiting room. He figures that her chronic headaches can wait while he treats the hemorrhaging accident patient. This is preemptive priority. The high priority accident patient can "bump" the lower priority customer out of the service facility. Heathcote (5) has done some work on preemptive discipline models.

Douglas: I'll guess that "resume" means that the bumped customer takes up its service where it left off when interrupted. Then "repeat" must mean that the customer must start its service cycle all over again.

Hugh: Correct. Up to this point we have been considering only two types of customers, one with high and one with low priority. However it is conceivable that three or more levels of customers might exist. This has even been generalized to a continuous number of priority types by Koenigsberg (6). As you can see the queue discipline is an important point in selecting an appropriate queueing model.

Douglas: The arrival distribution is undoubtedly the manner in which customers arrive and become a part of the queue.

Hugh: The two extreme arrival patterns are the constant and the exponential. With constant arrivals the customer arrives at exactly time t after the arrival of the previous customer. For example, consider an engine block being discharged from a transfer machine onto a conveyor to carry it to the next operation. If the transfer machine indexes every 80 seconds, then an engine block will arrive at the next operation every 80 seconds—constant arrivals. In the exponential case the customers arrive at random intervals. The name comes from the fact that the exponential function provides a good description of the cumulative probability distribution of intervals between successive arrivals. Frequently this pattern is called Poisson arrivals because the Poisson formula predicts the probability of obtaining various quantities of arrivals per unit time if the average quantity of arrivals per unit time is shown. The exponential pattern for random arrivals is without a doubt the most useful in practical applications.

Douglas: When are the hyper-exponential and Erlang

distributions used?

Hugh: The hyper-exponential is a rather specialized case where there is an increased appearance of very short and very long arrival intervals, that is, "bunches" of very short and very long intervals show up more often than in the exponential case. The Erlang arrival distributions are a family of distributions which vary from the "pure random" exponential type to the completely deterministic or constant arrival distribution. Morse describes all of these arrival patterns in his book (9).

Douglas: I presume that the service distributions have to do with the duration of the time required to provide the service and discharge the customer. I notice that the same four distributions are mentioned under service distribution as were indicated under arrival distributions.

Hugh: Yes, the properties are almost identical. The constant service case can be illustrated by the automatic car washer where a car comes off the line every 4 minutes. Exponential service would be applicable to the service man repairing down machines; each job would be somewhat different than the previous hence the service time could be considered to vary at random around some mean. The hyper-exponential and Erlang distributions have the same properties here as mentioned earlier.

Douglas: Your chart clears the air for me about queueing models. I am going to look at our inventory problem with this in mind. May I call upon you for further technical advice?

Hugh: By all means, but I think now that you should be able to define the model applicable to your problem. Just remember the five characteristics that you must pin down: a. the customer population, b. the number of channels, c. the queue discipline, d. the arrival distribution and e. the service distribution. When you have done this, I'll assist you with the mathematics. Perhaps you would like to review the Shelton article (12) and the chapter on queueing in Saaty (11) both of which are good summaries of the math involved. I've got to go out and check some troubles in Department 11, but meanwhile perhaps you'd like to make a copy of the chart to assist you in determining your model. See you later. *(Hugh exits, Curtain.)*

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(1) Barrer, D. Y., "Queuing with Impatient Customers and Indifferent Clerks," *Journal of the Operations Research Society of Ameria*, Vol. 5, No. 5, October 1957.

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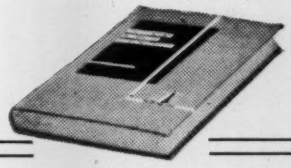

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Time Study Sample Size—The Effect of Effort Rating Variation

by **DAVID A. THOMPSON**

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IT HAS long been recognized that the larger the sample size in time study (i.e., number of cycles timed) the more accurate the study. Beyond a certain point, however, the additional accuracy is not needed and thus represents an avoidable cost. Some recent texts and articles determine analytically what sample size is needed for an individual element to obtain a certain accuracy of the average time at a given confidence level (1) (2) (3) (7). Stated differently, the problem is to find the most economical time study sample size such that the sample average time, $\overline{X}$, is within 100 ϵ % of the true mean with a probability of $(1-\alpha)$.

MINIMUM SAMPLE SIZE

Symbolically, the problem is to find the minimum sample size such that $\overline{X}$ will satisfy:

$$P_R[\overline{X} - \epsilon\overline{X} < \mu < \overline{X} + \epsilon\overline{X}] \geq 1 - \alpha \quad \text{Eq. 1.}$$

where:

μ = The true (unknown) population mean

$\overline{X}$ = The arithmetic mean of the sample which is taken to estimate the population mean

ϵ = The permissible error of the average (mean) time, chosen arbitrarily

α = The error of Type I, and $(1-\alpha)$ is the confidence level

From their basic definitions,

$$P_R[\overline{X} - K_{\alpha/2}\sigma_{\bar{x}} < \mu < \overline{X} + K_{\alpha/2}\sigma_{\bar{x}}] = 1 - \alpha \quad \text{Eq. 2.}$$

where:

$\sigma_{\bar{x}}$ = the standard deviation of the mean, or $\sigma_x/\sqrt{N}$

σ_x = the standard deviation of the element times X_k, where $k = 1, 2, \cdots, N$.

$K_{\alpha/2}$ = that number such that $\pm K_{\alpha/2}$ standard deviations on either side of the mean includes $(1-\alpha)$ fraction of the area under a standardized normal frequency distribution; thus $\pm K_{\alpha/2}\sigma_{\bar{x}}$ includes $100(1-\alpha)$ percent of the area under the distribution of the $\overline{X}$'s. Stated differently, $(1-\alpha)$ is the probability that a randomly selected $\overline{X}$ will fall within $K_{\alpha/2}\sigma_{\bar{x}}$ of the true mean provided one is sampling from a stable population (where the only principle variation is random variation). The implied assumption here is that, although the X_k's may not necessarily be normally distributed, an $\overline{X}$ formed from randomly selected X_k's will tend to be a normally distributed random variable.

Thus at the $(1-\alpha)$ confidence level, μ will fall within the range $\overline{X} \pm K_{\alpha/2}\sigma_{\bar{x}}$. From Eq.1., we wish μ to fall within $\overline{X} \pm \epsilon\,\overline{X}$. To accomplish this,

$$\pm\,\epsilon\overline{X} \geq \pm\,K_{\alpha/2}\sigma_{\bar{x}} \quad \text{Eq. 3.}$$

or the permissible error of the mean, $\epsilon\overline{X}$, constrains the spread of the distribution of sample means (from which one sample mean will be chosen at random through time study). Eq. 3., may be reduced to:

$$\epsilon\overline{X} \geq K_{\alpha/2}\sigma_{\bar{x}}$$

$$\geq K_{\alpha/2}\sigma_x/\sqrt{N}$$

$$N \geq \left(\frac{K_{\alpha/2}\sigma_x}{\epsilon\overline{X}}\right)^2 \quad \text{Eq. 4.}$$

where N is the minimum number of cycles to time when observing a work element in an equilibrium (constant cause) situation, so as to obtain $\pm 100\epsilon\%$ accuracy of the element mean or better, $100(1-\alpha)\%$ of the time; this will fulfill the requirements of Eq. 1. The procedure generally followed, then, is to calculate N for each element in the work to be studied, and then time study at least N_{max} cycles.

RATING VARIATION

This procedure does not give effect to the total variation in the finished standard time, however. It omits a principal source of variation—and perhaps the largest source of variation—leveling, or effort rating. In addition, timing only N_{max} cycles treats the variation of a sum of random variables incorrectly. In order to consider all sources of variation, Eq. 4. should be based on a distribution of standard times rather than just average times, where the standard time in its most generally accepted form is:

$$\text{S.T.} = (\overline{X})(\overline{L})(1 + A) \quad \text{Eq. 5.}$$

where $\overline{L}$ is the average leveling or effort rating estimate, and A is the assigned allowance factor, a constant for any

one job (calculated as in (2), p. 389). To simplify the discussion immediately following, consider the job to consist of only one element; in any event, let $\overline{X}$ and $\overline{L}$ be total job cycle averages.

Then the expected value of $(X)(L)(1+A)$ should be substituted for $\overline{X}$, and the square root of the variance of $(X)(L)(1+A)$ should be substituted for $\sigma_{\bar{x}}$, in Eq. 2. These new terms are derived in the appendix and are found to be (using their estimators):

$$E[(X)(L)(1+A)] = (\overline{X}\overline{L} + rs_x s_L)(1+A) \quad \text{Eq. 6.}$$

where:

r = an estimate of the correlation coefficient between X and L

s_x = an estimate of the standard deviation of the random variable X_k

s_L = an estimate of the standard deviation of the random dom variable L_k

$$\text{Var}\,[(X)(L)(1+A)] = (1+A)^2[(s_x^2 + \overline{X}^2)(s_L^2 + \overline{L}^2) + (rs_x s_L + \overline{X}\overline{L})^2 - 2\overline{X}^2\overline{L}^2] \quad \text{Eq. 7.}$$

Eq. 4. now becomes:

$$N \geq \frac{K_{\alpha/2}^2\,\text{Var}\,[(X)(L)(1+A)]}{\epsilon^2\{E[(X)(L)(1+A)]\}^2}$$

$$\geq \frac{K_{\alpha/2}^2(1+A)^2}{\epsilon^2} \cdot \left[\frac{(s_x^2 + \overline{X}^2)(s_L^2 + \overline{L}^2) + (rs_x s_L + \overline{X}\overline{L})^2 - 2\overline{X}^2\overline{L}^2}{(rs_x s_L + \overline{X}\overline{L})^2(1+A)^2}\right] \quad \text{Eq. 8.}$$

$$N \geq \frac{K_{\alpha/2}^2}{\epsilon^2}\left[\frac{(s_x^2 + \overline{X}^2)(s_L^2 + \overline{L}^2) - 2\overline{X}^2\overline{L}^2}{(rs_x s_L + \overline{X}\overline{L})^2} + 1\right] \quad \text{Eq. 9.}$$

Note that if s_L in Eq. 9. approaches zero, then Eq. 9. becomes the original statement in Eq. 4. That is, if the leveling estimate were known precisely (i.e., if it were not a random variable), then Eq. 4. would be applicable. Since, however, the leveling estimate *does* introduce a major source of variation (7, Ch. 23), Eq. 9. should be used.

It should be noted explicitly that the expected value of XL is approximately normally distributed as was $\overline{X}$, so that the approach of the initial derivation, based on normality, still applies. The term $(1+A)$ has dropped out of Eq. 9. indicating, as one might suspect, that sample size is independent of allowances which, in turn, we assumed in the appendix to be independent of XL.

One could argue that, granted the approximate normality of the relationships in the underlying model, once statistical estimators are substituted for the population parameters, $\overline{X}$ would have a t distribution instead of a normal distribution. This is true. But the only effect of this change in Eq. 9. would be to change the values for $K_{\alpha/2}$ only slightly. For example, later in this presentation I suggest using, for $\alpha = 0.05$, a $K_{\alpha/2}$ of 2. Strictly speaking, $K_{\alpha/2}$ should be 1.96 assuming normality and 2.06 assuming a t distribution, for a sample of 25. For time studies with fewer than 20 or so observations, it becomes important to use for $K_{\alpha/2}$ the 100α percentage points of the t distribution. However, since most studies contain more observations than this, using a $K_{\alpha/2}$ of 2 seems to be a reasonable practical modification. The reader will recall that $K_{\alpha/2}(t)$ approaches $K_{\alpha/2}$ (normal) as N increases.

OBSERVER BIAS

A little further explanation of the new terms in Eq. 9. perhaps would be helpful. s_L is the standard deviation of the random variable leveling estimate, and as such is a measure of the dispersion of the leveling estimates made by the time study analyst. An analyst may determine his own particular s_L by analyzing data collected while observing standardized effort rating films. A plot of "own estimate" versus "actual," often used in conjunction with the rating films, allows the analyst to estimate also any consistent bias that he may have in order to adjust his observed leveling factor accordingly.[1] In the event that s_L varies significantly for different levels of effort, that s_L which applies in the area of $\overline{L}$ for a given study may be used.

Note that in using the procedure summarized by Eq. 9., s_L need not be small. That is, the analyst need not be very precise in his leveling estimate. It is only necessary that his precision, as measured by s_L, be known and consistent on a short run basis (from one observation of a rating film to the next). Of course, the larger the s_L, the larger will be the sample size, N, to maintain the same precision of the standard time, hence, the more expensive the study.

Theoretically, the foregoing procedure involves collecting paired data, X_k and L_k for each work cycle. In practice, however, estimating an effort level associated with each measured time may be difficult, especially for short cycles. The greater the number of leveling estimates made during the study, the greater are the chances for precision. But the leveling phase of the study should not be burdensome for the analyst, to the detriment of other phases of the study.

Should it become necessary for the analyst to make only one overall, representative estimate of $\overline{L}$ directly, rather than computing $\overline{L}$ from individually observed L_k's, then a simplification of Eq. 7. may be made. The overall $\overline{X}$ and $\overline{L}$ are no longer dependent and the estimate of the correlation coefficient, r, may be considered to be zero.

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[1] Reference (7, p. 438) plots these relationships and (6, pp. 450–462) computes, plots, and explains the value of s_L in improving rating technique. The suggested approach assumes, as the author has found in practice, that reliable rating or leveling accuracy may be achieved from the observation of pace rating films. See (4).

PROCEDURE FOR APPLICATION

The setting of a standard time using the approach presented in this article is generally as follows:

1. Establish a reasonable level of accuracy, ϵ, for the standard time; $\pm 5\%$ is often used but $\pm 10\%$ is more economical and may be sufficient for many purposes. Establish the level of confidence, $(1-\alpha)$, wanted in the accuracy; 95% is often used ($K_{.05/2}=2$), but occasionally 99% is used ($K_{.01/2}=3$) although it more than doubles N.

2. Using standard time study procedures, time and level a preliminary study of 20 or so cycles. From these data compute (for a sample of size m)

$$\bar{X} = \frac{\sum_{k=1}^{m} X_k}{m}, \qquad \bar{L} = \frac{\sum_{k=1}^{m} L_k}{m}, \qquad s_x = \sqrt{\frac{\sum_{k=1}^{m} (X_k - \bar{X})^2}{m-1}},$$

and

$$r = \frac{\sum_{k=1}^{m} (X_k - \bar{X})(L_k - \bar{L})}{\sqrt{\sum_{k=1}^{m} (X_k - \bar{X})^2 \sum_{k=1}^{m} (L_k - \bar{L})^2}}.$$

s_L has been previously determined by the time study analyst. Eq. 9. will then give a first approximation of the sample size necessary to achieve an accuracy within 100 ϵ%, at a confidence level of $1-\alpha$, for the total standard time.

3. If $N > m$, take at least $N-m$ additional observations. If desired, N may be recomputed at this point to determine if it has changed significantly from the N found in step 2.

Up to this point, the proposed procedure has been developed in terms of a one-element job, and the statistics developed have applied to the total cycle time. This is of course not the usual condition. When a number of elements occur each cycle, $\bar{X}$ would be the sum of the average element times; $\bar{L}$ would be the weighted average of the average element leveling estimates; s_x^2 woul l be the sum of the element time variances; s_L^2 would be the weighted sum of the element leveling variances, provided the latter vary between the elements; and r is the weighted average of the element correlations. Everything else would remain as before. This approach assumes mutual independence between the elements, a situation probably not precisely correct but the assumption seems to be a reasonable one.

The approach suggested by this article is not necessarily recommended for all time study situations. The complexity of a given time study should be no more than economically feasible. Obviously, Eq. 9. requires more than the normal amount of calculation. However, when it is desired to obtain a high degree of accuracy in the total standard time, and/or to know precisely what accuracy is being obtained, then the approach presented herein is suggested.

SUMMARY

A technique is developed and presented which calculates the minimum time study sample size necessary to achieve any arbitrarily high degree of precision in the overall standard time, regardless of the amount of variation in the various estimates involved (including the leveling or effort rating estimate). The amount of variation needs only to be known and should be relatively consistent in the short run.

Therefore, provided one is sampling from a stable situation, this article challenges the contention by some critics that time study cannot be a precise measuring technique.

APPENDIX

The bivariate normal distribution of two dependent random variables, X and L, has a moment generating function (5, pp. 166–7) of:

$$\begin{aligned} m(t_1, t_2) &= E\left[e^{t_1 X + t_2 L}\right] \\ \log m(t_1, t_2) &= t_1\mu_x + t_2\mu_L + \tfrac{1}{2}t_1^2\sigma_x^2 + \rho t_1 t_2 \sigma_x \sigma_L + \tfrac{1}{2}t_2^2\sigma_L^2 \\ &= t_1(\mu_x + \rho t_2 \sigma_x \sigma_L) + \tfrac{1}{2}t_1^2\sigma_x^2 + t_2\mu_L \\ &\quad + \tfrac{1}{2}t_2^2\sigma_L^2 \end{aligned} \qquad \text{Eq. I}$$

where:

μ_x = the mean of the population of X's
μ_L = the mean of the population of L's
σ_x = the standard deviation of X
σ_L = the standard deviation of L
ρ = the correlation coefficient of X and L

$$\begin{aligned} \log \frac{\partial m}{\partial t_1} &= \log(\mu_x + \rho t_2 \sigma_x \sigma_L + t_1 \sigma_x^2) + t_1(\mu_x + \rho t_2 \sigma_x \sigma_L) \\ &\quad + \tfrac{1}{2}t_1^2\sigma_x^2 + t_2\mu_L + \tfrac{1}{2}t_2^2\sigma_L^2 \\ &= \log(\mu_x + \rho t_2 \sigma_x \sigma_L + t_1 \sigma_x^2) + t_2(\mu_L + \rho t_1 \sigma_x \sigma_L) \\ &\quad + \tfrac{1}{2}t_2^2\sigma_L^2 + t_1\mu_x + \tfrac{1}{2}t_1^2\sigma_x^2 \end{aligned}$$

$$\begin{aligned} \log \frac{\partial}{\partial t_1}\frac{\partial m}{\partial t_2} &= \log\left[\rho\sigma_x\sigma_L + (\mu_x + \rho t_2\sigma_x\sigma_L + t_1\sigma_x^2)\right. \\ &\qquad \left.\cdot(\mu_L + \rho t_1\sigma_x\sigma_L + t_2\sigma_L^2)\right] \\ &\quad + t_2(\mu_L + \rho t_1\sigma_x\sigma_L) + \tfrac{1}{2}t_2^2\sigma_L^2 + t_1\mu_x \\ &\quad + \tfrac{1}{2}t_1^2\sigma_x^2 \end{aligned} \qquad \text{Eq. II}$$

$$\begin{aligned} \left.\frac{\partial}{\partial t_1}\frac{\partial m}{\partial t_2}\right|_{t_1,\ t_2=0} &= \mu_x\mu_L + \rho\sigma_x\sigma_L \\ &= E[XL] \end{aligned} \qquad \text{Eq. III}$$

The best estimate of the expected value of XL is:

$$E[XL] = \overline{XL} + r s_x s_L \qquad \text{Eq. IV}$$

Then:

$$E[XL(1+A)] = (\overline{XL} + r s_x s_L)(1+A) \qquad \text{Eq. V}$$

since XL and the constant $(1+A)$ are independent.

Eq. II may be differentiated again with respect to t_1 to get:

$$\begin{aligned} \log \frac{\partial^2 m}{\partial t_1^2} &= \log\left[(\mu_x + \rho t_2\sigma_x\sigma_L + t_1\sigma_x^2)^2 + \sigma_x^2\right] \\ &\quad + t_1(\mu_x + \rho t_2\sigma_x\sigma_L) + \tfrac{1}{2}t_1^2\sigma_x^2 + t_2\mu_L + \tfrac{1}{2}t_2^2\sigma_L \\ &= \log\left[(\mu_x + \rho t_2\sigma_x\sigma_L + t_1\sigma_x^2)^2 + \sigma_x^2\right] \\ &\quad + t_2(\mu_L + \rho t_1\sigma_x\sigma_L) + \tfrac{1}{2}t_2^2\sigma_L + t_1\mu_x + \tfrac{1}{2}t_1^2\sigma_x^2 \end{aligned}$$

$$\log \frac{\partial^2}{\partial t_1^2}\frac{\partial m}{\partial t_2} = \log\{2\rho\sigma_x\sigma_L(\mu_x + \rho t_2\sigma_x\sigma_L + t_1\sigma_x^2) + [(\mu_x + \rho t_2\sigma_x\sigma_L + t_1\sigma_x^2)^2 + \sigma_x^2] \cdot [\mu_L + \rho t_1\sigma_x\sigma_L + t_2\sigma_L^2]\} + t_2(\mu_L + \rho t_1\sigma_x\sigma_L) + \tfrac{1}{2}t_2^2\sigma_L^2 + t_1\mu_x + \tfrac{1}{2}t_1^2\sigma_x^2$$

$$\log \frac{\partial^2}{\partial t_1^2}\frac{\partial^2 m}{\partial t_2^2} = \log\{2\rho^2\sigma_x^2\sigma_L^2 + [2(\mu_x + \rho t_2\sigma_x\sigma_L + t_1\sigma_x^2)\rho\sigma_x\sigma_L] \cdot (\mu_L + \rho t_1\sigma_x\sigma_L + t_2\sigma_L^2) + [(\mu_x + \rho t_2\sigma_x\sigma_L + t_1\sigma_x^2)^2 + \sigma_x^2]\sigma_L^2 + [2\rho\sigma_x\sigma_L(\mu_x + \rho t_2\sigma_x\sigma_L + t_1\sigma_x^2) + \{(\mu_L + \rho t_2\sigma_x\sigma_L + t_1\sigma_x^2)^2 + \sigma_x^2\} \cdot (\mu_L + \rho t_1\sigma_x\sigma_L + t_2\sigma_L^2)] \cdot (\mu_L + \rho t_1\sigma_x\sigma_L + t_2\sigma_L^2)\} + t_2(\mu_L + \rho t_1\sigma_x\sigma_L) + \tfrac{1}{2}t_2^2\sigma_L^2 + t_1\mu_x + \tfrac{1}{2}t_1^2\sigma_x^2$$

$$\left.\frac{\partial^2}{\partial t_1^2}\frac{\partial^2 m}{\partial t_2^2}\right|_{t_1,t_2=0} = (\sigma_x^2\sigma_L^2 + \sigma_x^2\mu_L^2 + \sigma_L^2\mu_x^2 + \mu_x^2\mu_L^2) + (2\rho^2\sigma_x^2\sigma_L^2 + 4\rho\sigma_x\sigma_L\mu_x\mu_L)$$
$$= (\sigma_x^2 + \mu_x^2)(\sigma_L^2 + \mu_L^2) + 2(\rho\sigma_x\sigma_L + \mu_x\mu_L)^2 - 2\mu_x^2\mu_L^2 \quad \text{Eq. VI}$$

by completing the square of the second term. Using this result to find the variance of the distribution of standard times:

$$\begin{aligned}
&\text{Var}\,[(X)(L)(1+A)] \\
&= (1+A)^2\,\text{Var}\,[XL] \\
&= (1+A)^2 E[XL - E(XL)]^2 \\
&= (1+A)^2\{E[X^2L^2] - [E(XL)]^2\} \\
&= (1+A)^2[(\sigma_x^2 + \mu_x^2)(\sigma_L^2 + \mu_L^2) + 2(\rho\sigma_x\sigma_L + \mu_x\mu_L)^2 \\
&\quad - 2\mu_x^2\mu_L^2 - (\rho\sigma_x\sigma_L + \mu_x\mu_L)^2] \qquad \text{Eq. VII}
\end{aligned}$$

since

$$E[X^2L^2] = \left.\frac{\partial^2}{\partial t_1^2}\frac{\partial^2 m}{\partial t_2^2}\right|_{t_1,t_2=0}$$

from Eq. VI and

$$E[XL] = \rho\sigma_x\sigma_L + \mu_x\mu_L.$$

Eq. VII reduces to:

$$\begin{aligned}
&\text{Var}\,[(X)(L)(1+A)] \\
&= (1+A)^2[(\sigma_x^2 + \mu_x^2)(\sigma_L^2 + \mu_L^2) + (\rho\sigma_x\sigma_L + \mu_x\mu_L)^2 - 2\mu_x^2\mu_L^2] \qquad \text{Eq. VIII} \\
&\approx (1+A)^2[s_x^2 + \overline{X}^2)(s_L^2 + \overline{L}^2) + (rs_xs_L + \overline{XL})^2 - 2\overline{X}^2\overline{L}^2] \qquad \text{Eq. IX}
\end{aligned}$$

in terms of the estimators used to compute the variance.

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Statistical Tolerance Limits for Determining Process Capability[1]

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THE permissible amount of variation in the quality characteristic of a manufactured product is largely an economic matter. In setting a specification to be held in manufacture, the designer must weigh the precision required in the final product against the costs of obtaining it. Too tight tolerances are bound to raise the cost, while the value of the end product will suffer if the tolerances are too loose. It is desirable that an economic balance be reached.

Part of the problem is solved by reference to handbook data, industrial standards and the designer's experience. While these data furnish a starting point, they seldom relate exactly to the problem at hand. Several important considerations are not resolved; for example, the relative difficulty of obtaining the tolerance at the particular facility, and how the tolerance will be proportioned among various related characteristics.

To resolve these problems, the designer may be able to take into consideration the capabilities of the process which will be used in manufacture, if it is possible to obtain samples from the process.

Efforts have been made over the years to provide a method of setting tolerances through the use of statistical quality control. By sampling the output of a process, it is possible to estimate the true average value and the true variability which is inherent in that process. Using these estimates, statistical tolerance limits can be set to have a high probability of including a given proportion of the product. With this information, the designer may be able to take better advantage of the process.

The aim of this article is to call attention to a means of directly determining the tolerance limits when the characteristic under study is approximately normally distributed. Techniques for determining tolerance limits, assuming a normal distribution, and assuming that the population average and standard deviation are *known* are used routinely in industry. The totality of these assumptions is usually very unrealistic. The methods given here do not make the assumption that the population values are known.

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THE NATURE OF TOLERANCE LIMITS

A rigorous knowledge of the mathematical background for tolerance limits is not required for their effective use. On the other hand, some general understanding of their development may prevent misuse of the technique. To that end a brief discussion will be given of the general nature of the concepts involved.

It is often assumed that a characteristic has a normal distribution. Where this assumption is justified it is useful as it allows objective statements about the population, which would not be possible if somewhat less restrictive assumptions were made. All tables given in this report depend on the characteristic having a normal distribution.

If the average and the standard deviation of a normal population are known, limits containing a specified proportion of the population can be calculated. Specifically an upper limit could be found such that 95% of the population would be less than that limit. Likewise, upper and lower limits could be calculated containing 95% of the population between them. To locate positively these limits the true population average and standard deviation must be known.

In industrial situations the true average and standard deviation are not known but rather must be estimated from a sample. The sample average can be used to estimate the population average. Either the sample range, sample average range, or sample standard deviation can be used to estimate the population standard deviation. The latter estimate is to be preferred.

All sample estimates depend on the particular sample that is chosen. A sample that contains several high readings might give a higher average than another sample which by chance contained only values close to the population average. Since the estimates will vary from sample to sample, it follows that limits based on them must also vary. These limits would still be useful if it were known how often the interval they include would account for at least a stated proportion of the population.

This article contains procedures for determining one-sided and two-sided tolerance limits. A one-sided upper tolerance limit is such that the probability is γ that at least a proportion P of the population is less than the limit. A one-sided lower tolerance limit is such that the propability is γ that at least a proportion P of the population is greater than the limit. Two-sided tolerance limits are a pair of limits such that the probability is γ that at least a proportion P, of the population falls within the interval included by the two limits. If the population mean μ and population standard deviation σ were known, tolerance intervals would be formed by adding to and subtracting from the mean a certain multiple K of the standard deviation; the appropriate value of K being determined from tables of the normal distribution. For example 90 percent of the population is included in the interval $\mu - 1.645\sigma$ to $\mu + 1.645\sigma$. In most practical situations the true values of μ and σ are not known. The population mean μ is replaced by the sample mean and the population standard deviation σ is replaced by a sample estimate, this estimate being either the sample range, the sample average range, or the sample standard deviation. The proportion of the population included in the resulting interval is a random quantity and it is impossible to determine K such that the limits will always contain a specified proportion of the universe. In this report the factors K are determined in such a way that in a large series of samples a certain proportion γ of the resulting intervals will include P or more of the population.

TABLE 1*

Tolerance Factors for Normal Distributions Utilizing the Sample Standard Deviation s. Factors K for one-sided tolerance limits such that the probability is γ that at least a proportion P of the distribution will be less than $\bar{x}+Ks$ (or greater than $\bar{x}-Ks$), where $\bar{x}$ and s are estimates of the mean and the standard deviation computed from a sample of size n.

n \ P	γ=0.95			γ=0.99		
	0.95	0.99	0.999	0.95	0.99	0.995
3	7.655	10.552	13.857			
4	5.145	7.042	9.215			
5	4.202	5.741	7.501			
6	3.707	5.062	6.612	5.409	7.334	9.540
7	3.399	4.641	6.061	4.730	6.411	8.348
8	3.188	4.353	5.686	4.287	5.811	7.566
9	3.031	4.143	5.414	3.971	5.389	7.014
10	2.911	3.981	5.203	3.739	5.075	6.603
11	2.815	3.852	5.036	3.557	4.828	6.284
12	2.736	3.747	4.900	3.410	4.633	6.032
13	2.670	3.659	4.787	3.290	4.472	5.826
14	2.614	3.585	4.690	3.189	4.336	5.651
15	2.566	3.520	4.607	3.102	4.224	5.507
16	2.523	3.463	4.534	3.028	4.124	5.374
17	2.486	3.415	4.471	2.962	4.038	5.268
18	2.453	3.370	4.415	2.906	3.961	5.167
19	2.423	3.331	4.364	2.855	3.893	5.078
20	2.396	3.295	4.319	2.807	3.832	5.003
21	2.371	3.262	4.276	2.768	3.776	4.932
22	2.35	3.233	4.238	2.729	3.727	4.866
23	2.329	3.206	4.204	2.693	3.680	4.806
24	2.309	3.181	4.171	2.663	3.638	4.755
25	2.292	3.158	4.143	2.632	3.601	4.706
30	2.220	3.064	4.022	2.516	3.446	4.508
35	2.166	2.994	3.934	2.431	3.334	4.364
40	2.126	2.941	3.866	2.365	3.250	4.255
45	2.092	2.897	3.811	2.313	3.181	4.168
50	2.065	2.863	3.766	2.296	3.124	4.096
∞	1.645	2.326	3.090	1.645	2.326	3.090

* The tables have been abridged, complete tables for other values of P as well as companion tables based on the range and average range may be found in (2).

TABLE 2

Tolerance Factors for Normal Distributions Utilizing the Sample Standard Deviation s. Factors K for two-sided tolerance limits such that the probability is γ that at least a proportion P of the distribution will be included between $\bar{x}+Ks$, where $\bar{x}$ and s are estimates of the mean and the standard deviation computed from a sample of n.

n \ P	γ=.95			γ=.99		
	0.95	0.99	0.999	0.95	0.99	0.999
2	37.674	48.430	60.573	188.491	242.300	303.054
3	9.916	12.861	16.208	22.401	29.055	36.616
4	6.370	8.299	10.502	11.150	14.527	18.383
5	5.079	6.634	8.415	7.855	10.260	13.015
6	4.414	5.775	7.337	6.345	8.301	10.548
7	4.007	5.248	6.676	5.488	7.187	9.142
8	3.732	4.891	6.226	4.936	6.468	8.234
9	3.532	4.631	5.899	4.550	5.966	7.600
10	3.379	4.433	5.649	4.265	5.594	7.129
11	3.259	4.277	5.452	4.045	5.308	6.766
16	3.162	4.150	5.291	3.870	5.079	6.477
13	3.081	4.044	5.158	3.727	4.893	6.240
14	3.012	3.955	5.045	3.608	4.737	6.043
15	2.954	3.878	4.949	3.507	4.605	5.876
16	2.903	3.812	4.865	3.421	4.492	5.732
17	2.858	3.754	4.791	3.345	4.393	5.607
18	2.819	3.702	4.725	3.279	4.307	5.497
19	2.784	3.656	4.667	3.221	4.230	5.399
20	2.752	3.615	4.614	3.168	4.161	5.312
21	2.723	3.577	4.567	3.121	4.100	5.234
22	2.697	3.543	4.523	3.078	4.044	5.163
23	2.673	3.512	4.484	3.040	3.993	5.098
24	2.651	3.483	4.447	3.004	3.947	5.039
25	2.631	3.457	4.413	2.972	3.904	4.985
30	2.549	3.350	4.278	2.841	3.733	4.768
35	2.490	3.272	4.179	2.748	3.611	4.611
40	2.445	3.213	4.104	2.677	3.518	4.493
45	2.408	3.165	4.042	2.621	3.444	4.399
50	2.379	3.126	3.993	2.576	3.385	4.323
∞	1.960	2.576	3.291	1.960	2.576	3.291

THE APPLICATION OF TOLERANCE LIMITS

Several decisions are required before tolerance limits can be calculated. These are:

1. For what proportion of the population need we account?
2. How confident need we be that at least this proportion of the population be within the interval?

3. What sample size should be chosen?

4. Should the limits be based on the sample mean and the sample range, or on the sample mean and the sample standard deviation?

The choice in 4. is a matter of convenience only in so far as it affects the cost of data analysis. The situation is different from say, choosing between the use of sample range or sample standard deviation for a control chart. Here ease of calculation is important. On a control chart the calculation of the variation will be done repeatedly. Tolerance limits will not in general be recalculated as often as control chart data are entered. Often machine operators and patrol inspectors maintain control charts. Ordinarily these persons will not make tolerance limit studies. Even though the range is easier to calculate the sample standard deviation should be preferred. Only this method will be considered.[2]

The sample size is determined partly by considerations of economy and partly by the acceptable level of risk or uncertainty. Larger samples will be more costly to obtain and to analyze. Larger samples do have the advantage that estimates from them will have a smaller variation around the true population values therefore the K factor decreases with increasing sample size. While the decrease is quite large for moderate increases in sample size when the sample is small, a large increase in an already large sample gives little improvement. The minimum value of K is obtained for an infinitely large sample. At this point K is the usual factor for the area under the normal curve.

A reasonable guide for selecting the sample size is to use the largest number possible up to, say, 100. Beyond 100 the improvement is small even for an increase by a power of ten.

The proportion of the population and the confidence level can not truly be decided independently. Short of a full economic analysis, it is probably best to treat the proportion as an economic problem and to set the value of γ to meet the requirments of the application. If, for instance, exceeding a particular limit will cause assembly trouble, then it is only reasonable to require an economical percentage of the product to be less than this value. Possibly one defective piece in one hundred would be an acceptable level. If so, then $P = 0.99$ would be chosen.

The choice of the level of confidence is similar to choosing between 2 sigma or 3 sigma control limits for a control chart. On control charts it is customary to use three sigma limits. These limits give approximately 0.3 per cent chance of declaring that the process has changed when in fact no change has occurred. This implies that this risk on this error is acceptable. In setting tolerance limits, selection of $\gamma = 0.99$ would imply the acceptance of a risk of making an incorrect statement concerning P equal to one per cent.

The probability statement for tolerance limits is that the probability is γ that at least P per cent of the population lies between the limits. Once a sample is drawn and the limits calculated the probability statement loses meaning. It is obvious that any particular set of limits must either contain at least P per cent or not contain that percentage. Consequently if the statement is made that the limits contain P per cent of the distribution, then in a long series of such statements γ per cent of these statements will be correct.

Drawing the sample should be done in a truly random manner taking into account that the tolerance limits will apply only to the particular circumstances which apply to the sample. Thus many measurements from the same piece permit a statement only about that piece. Likewise pieces drawn from the same spindle or the same machine restrict the usefulness of the limits to material from those sources.

The units drawn as a sample for computing tolerance limits must come from a stable source. For instance, this would mean that data taken from a control chart could only be used if the process is in control. A controlled process has had all assignable causes eliminated. Thus even if the units came from several machines the stable source requirement may be fulfilled.

Actual application of the tolerance limits can best be shown by example. Several representative samples follow. They illustrate the use of the tables for making process capability studies, setting tolerances and comparing the process specifications. This last use comes the closest to the use of the tables for construction of variable sampling plans. While such an interpretation is possible, the plans so developed would have little practical value.

In the following discussion $\overline{X}$ denotes the sample mean. If $X_1, X_2, \cdots, X_n$, are the n sample values then

$$\overline{X} = \frac{X_1 + X_2 + \cdots + X_n}{n} = \sum_{i=1}^{n} X_{i/n}.$$

The symbol

$$s = \sqrt{\sum_{i=1}^{n} (X_i - \overline{X})^2/_{n-1}}$$

denotes the sample standard deviation.

EXAMPLE 1. WAFER LAPPING

A process capability application of tolerance limits based on the sample standard deviation.

A transistor manufacturer has an intermediate processing step which consists of lapping a crystal wafer for thickness control. While this thickness does not affect the characteristics of the resulting device, it does influence several intermediate steps.

Etching is one operation affected. This operation can be adjusted to accommodate almost any thickness, but excessive losses result if etching conditions differ greatly from the best conditions for the particular thickness being etched.

[2] Tolerance limits for the normal distribution based on the range and average range are found in (2), (5) and (7).

In order to minimize losses in both time and product, it is desired to know where the majority of the lapped wafer thicknesses will fall. Economy suggests that the etching process should accommodate about 90% of the incoming (lapped wafers) accepting a risk of exceeding this level only 5% of the time. Wafers from several runs are measured, giving the results shown in Figure 1.

Proportion of the population $P = 0.90$ Characteristic Thickness

Required level of confidence $\gamma = 0.95$ Source Lapping Operation

Unit of Measure Microns

No.	Reading	Readings Squared
1	71	
2	90	
3	90	
4	90	
5	75	
6	75	
7	85	
8	86	
9	86	
10	76	
11	70	
12	86	
13	86	
14	87	
15	77	
16	84	
17	74	
18	75	
19	74	
20	84	
21	73	
22	82	
23	84	
24	88	
25	80	
26	86	
27	78	
28	74	
29	87	
30	70	
31		
32		
33		
34		
35		
36		
37		
38		
39		
40		
Sum $= \Sigma X$	2.423	196.941

$= \Sigma X^2 =$ Sum of squares

1. Calculate the average $\bar{X}$

$$\bar{X} = \frac{\Sigma X}{n} = \cdots = 80.73$$

where n is the total number of readings.

2. Calculate the standard deviation

$$s = \frac{\sqrt{\Sigma X^2 - \frac{(\Sigma X)^2}{n}}}{n-1} = 6.55$$

3. For a one-sided tolerance, find K on table _____ ($K =$ _____) for the specified sample size, P and γ.
The probability is (γ) _____ that at least (P) _____ of the population is: a. Less than the Upper Tolerance Limit $\bar{X} + Ks =$ _____ + _____ = _____ or: b. Greater than the Lower Tolerance Limit $\bar{X} - Ks =$ _____ − _____ = _____

4. For a two-sided tolerance, find K on Table 2 ($K = 2.140$) for the specified sample size, P and γ. The probability is (γ) 0.95 that at least (P) 0.90 of the population is between: Upper Tolerance Limit $= \bar{X} + Ks = 80.73 + 2.140 \times 6.55 = 94.96$ and Lower Tolerance Limit $= \bar{X} - Ks = 80.73 - 2.140 \times 6.55 = 66.50$.

FIGURE 1. Tolerance Limits—Based on the Standard Deviation

Discussion of Example 1

The example shows the use of tolerance limits for a typical process capability study. Here the purpose was not to determine whether the process was producing acceptable material but rather to determine what range of product the subsequent operation should be capable of accommodating.

Commonly, process capability studies are made somewhat differently. It might well be asked what difference would result if the sample statistics $\bar{x}$ and s had been considered reasonable estimates of the population parameters μ and σ. In this case the process limits would be $\mu + K_\alpha\sigma$ and $\mu - K_\alpha\sigma$ where $1 - 2\alpha$ is the proportion P. ($P = .90$ so that $\alpha = .05$.) K_α may be obtained from the tables of the cumulative normal deviate. Since knowledge of μ and σ is assumed, γ equals 1. In this case the limits would be:

$$\mu + K_\alpha\sigma = 80.73 + 1.645(6.55) = 91.49$$
$$\mu - K_\alpha\sigma = 80.73 - 1.645(6.55) = 69.97.$$

The results obtained by the use of tolerance limit factors (94.96, 66.50) have given a wider range for process capability. This is to be expected since the interpretation of the two procedures is quite different. If the population parameters μ and σ were known, then the calculated limits will contain a fixed known proportion of the population with probability 1.

When μ and σ are unknown the sample values must be used to estimate them. Now $\bar{x}$ and s are chance quantities which will vary from sample to sample. Therefore limits derived from them can also be expected to vary from sample to sample. This chance variation must be taken into account if it is desired to locate tolerance limits such that at least a fixed proportion of the population will be contained within them, with a given degree of assurance.

Once it is decided that the limits should contain, say, 95% of the population it must next be asked how confident you must be that this proportion will not be exceeded. In the example just cited the proportion of the population is 90%. At least this proportion will be between the limits 95% of the time.

EXAMPLE 2. SATURATION VOLTAGE

Application of one-sided tolerance limits to transistor characteristics.

Vacuum tubes, transistors etc. are commonly advertised with characteristic curves showing the mean value at some operating condition plus an upper and lower limit for this characteristic. These upper and lower limits are derived from percentile points of the sample. Since percentile points do not take into account the size of the sample, curves based on them may conceal a large experimental error.

Consider the d.c. saturation voltage between collector and emitter with specified base and collector currents. This is an important characteristic of a switching transistor. For it a maximum specification is sufficient.

Proportion of the population $P = 0.95$ Characteristic Saturation Voltage

Required level of confidence $\gamma = 0.99$ Source Final Inspection Unit of Measure Volts

No.	Reading	Readings Squared
1	0.84	
2	0.43	
3	0.50	
4	0.50	
5	0.79	
6	0.63	
7	0.52	
8	0.59	
9	0.52	
10	0.62	
11	0.64	
12	0.62	
13	0.60	
14	0.65	
15	0.79	
16	0.70	
17	0.54	
18	0.70	
19	0.63	
20	0.67	
21	0.68	
22	0.70	
23	0.82	
24	0.62	
25	0.56	
26		
27		
28		
29		
30		
31		
32		
33		
34		
35		
36		
37		
38		
39		
40		
Sum $= \Sigma X$	15.86	10.3256

1. Calculate the average $\bar{X}$

$$\bar{X} = \frac{\Sigma X}{n} = \frac{15.86}{25} = 0.6344$$

where n is the total number of readings.

2. Calculate the standard deviation

$$s = \frac{\sqrt{\Sigma X^2 - \frac{(\Sigma X)^2}{n}}}{n-1} = 0.10488$$

3. For a one-sided tolerance, find K on Table 1 ($K = 2.632$) for the specified sample size, P and γ. The probability is (γ) 0.99 that at least (P) 0.95 of the population is: a. Less than the Upper Tolerance Limit $\bar{X} + Ks = 0.6344 + 2.632 \times 0.10488 = 0.9104$ or: b. Greater than the Lower Tolerance Limit $\bar{X} - Ks =$ _____ $-$ _____ $\times$ _____ $=$ _____.

4. For a two-sided tolerance, find K on Table 2 ($K =$ _____) for the specified sample size, P and γ. The probability is (γ) _____ that at least (P) _____ of the population is between: Upper Tolerance Limit $= \bar{X} + Ks =$ _____ $+$ _____ $\times$ _____ $=$ _____ and Lower Tolerance Limit $=$ _____ $-$ _____ $\times$ _____ $=$ _____.

$= \Sigma X^2 =$ Sum of squares

FIGURE 2. Tolerance Limits—Based on the Standard Deviation.

A manufacturer wishes to state in his advertised specifications the lowest maximum voltage which he feels confident of being able to achieve under normal manufacturing conditions. To determine the required tolerance limits a sample of 25 units has been tested. The results are presented in Figure 2. Since it is the industry practice to publish the 95 percent point, P has been set at 0.95 and γ has been chosen as 0.99 reflecting the need for a high degree of confidence.

Completing the calculations in Figure 2 the upper tolerance limit under the stated conditions is 0.9104 volts.

Discussion of Example 2

This example suggests refinement in advertised specifications using tolerance limits. Under this system it would be appropriate to state both the percent of values expected to fall within the specification and the probability of this occurring. In this way the sample size will be reflected in the limits.

Naturally, the same limitations apply to this application as to all others, namely the underlying distribution should be well approximated by a normal curve. If this is not the case then tolerance limits based on a better fitting distribution should be used. If no satisfactory approximation is available, non-parametric tolerance limits should be used. A discussion of non-parametric tolerance limits, which do not assume knowledge of the frequency distribution may be found in (8).

APPENDIX

APPROXIMATION FORMULAE FOR COMPUTING TOLERANCE FACTORS FOR LARGE N

When the sample sizes are large, say in excess of 50 observations, certain approximations may be used to obtain tolerance factors for values of n, P, and γ not covered in the present report.

TWO-SIDED TOLERANCE LIMITS USING THE SAMPLE STANDARD DEVIATION

To find the value k, such that the interval $\bar{x} \pm ks$ includes at least the proportion P with probability γ, the following formula may be used:

$$k = \frac{K_{1-P}}{2}\left(1 + \frac{K_{1-\gamma}}{\sqrt{2n}} + \frac{5K_{1-\gamma}^2 + 10}{12n}\right)$$

For example for $P = .90$, $\gamma = .95$ and $n = 50$ we find,[3] since $K_{.05} = 1.645$, that

$$k = 1.645\left(1 + \frac{1.645}{\sqrt{100}} + \frac{5(1.645)^2 + 10}{12(50)}\right) = 1.980$$

This value differs from the more accurate figure of 1.992 by only one unit in the third significant figure. The discrepancy between the true value and the one yielded by the approximation diminishes as n increases, for this as well as for the other approximations given here.

[3] Each of the approximation formulae involves the use of the variable K_P, defined as the unit normal deviate exceeded with probability P. An extensive table of K_P may be found in *The Kelley Statistical Tables*, Macmillan Company, 1938.

ONE-SIDED TOLERANCE LIMITS USING THE SAMPLE STANDARD DEVIATION

To find the value k such that $[-\infty, \bar{x} + ks]$ (or $[\bar{x} - ks, -\infty]$) includes at least the proportion P with probability γ, the following formula may be used:

$$k = \frac{K_{1-P} - \sqrt{K_{1-P}^2 - \left(K_{1-P}^2 - \frac{K_{1-\gamma}^2}{n}\right)\left(1 - \frac{K_{1-\gamma}^2}{2(n-1)}\right)}}{\left(1 - \frac{K_{1-\gamma}^2}{2(n-1)}\right)}.$$

Using the previous example, with $K_{.10} = 1.2816$, we obtain

$$k = \frac{1.2816 + \sqrt{(1.2816)^2 - \left[(1.2816)^2 - \frac{(1.645)^2}{50}\right]\left[1 - \frac{(1.645)^2}{2(50-1)}\right]}}{\left[1 - \frac{(1.645)^2}{2(50-1)}\right]}$$

$$= 1.640$$

This value compares favorably with the more accurate value of 1.646 and differs from it by only one unit in the third significant figure.

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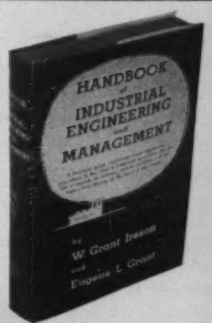

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A Queueing Model with State Dependent Service Rate*

by RICHARD W. CONWAY and WILLIAM L. MAXWELL

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IN THE course of studying a network of queues as a representation of a production shop we have become concerned with the rigidity of the usual queueing model (1). A network of service centers, all of which are theoretically equally loaded, experiences very considerable short-term variations in load that result in serious system unbalance. The disparity in state between the different centers in the network becomes very severe—some queues becoming very long while other centers are idle. While it is of course true that work-in-process in a production shop is not uniformly distributed among the various work centers, our experience suggests that the disparity of distribution in an actual shop is rarely as great as that encountered in our queueing model.

This might suggest that the actual shop possesses one or more defense mechanisms which are not present in our theoretical model. These would be adjustments that the system could make in order to improve the short-run balance between service centers. These adjustments are perhaps of three types:

A. *External*

The sequence of jobs released to the shop can be controlled so as to maintain a short-run balance of work-loads. This is commonly done and is called *machine loading*. However, in many cases this constitutes a form of self-deception—the actual external demand is not altered. A preliminary smoothing filter is inserted between the demand and the network. By allowing a backlog to build up behind this filter, work can be selected from this backlog to maintain a relatively good short-run balance in the queueing network.

Short-run peaks in load for individual service centers can be truncated by subcontracting operations requiring this type of service or entire jobs which have substantial requirements for this type of service.

The capacity of individual service centers can be adjusted by means of temporarily adding or removing equipment and/or men, or by altering the number of hours per day that the facilities are employed (overtime, undertiime, second shift).

B. *Network Discipline*

The network can take advantage of flexibility in discipline to attempt to level the work among centers. This flexibility includes:

1. Sequence of work at centers. Priority can be given to jobs which, for their next operation, move to a center which is starving for work.

2. Selection of machines. When the "preferred machine" for a given operation is overloaded with work, an "alternative machine" which is more lightly loaded can be employed to advantage, even if the operation takes somewhat longer on the alternate machine.

3. Flexibility of operators. The network may adjust the capacity of the different service centers internally by shifting men from one center to another as overloads develop.

4. Order of operations. In many cases the operations of a job

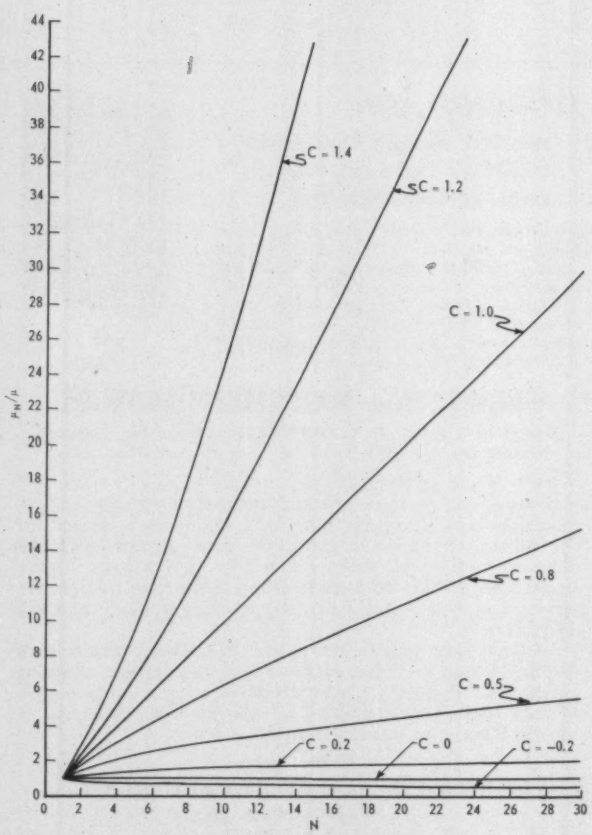

FIGURE 1. μ_n/μ as a Function of n for Different Values of c. $\mu_n = n^c\mu$.

* This article is based upon a research report of the Cornell Production Control Research Committee, a cooperative research project of Cornell University, The General Electric Company, and Touche, Ross, Bailey and Smart.

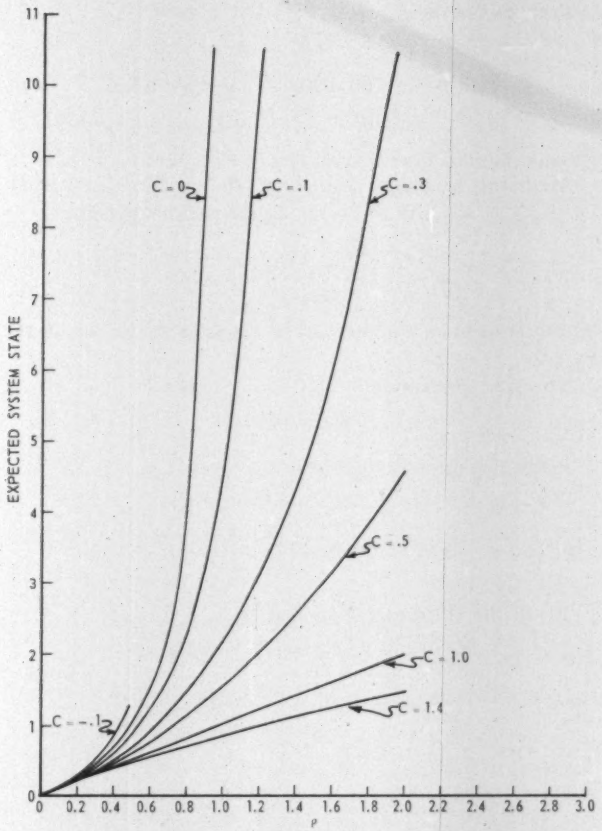

FIGURE 2. Expected System State versus Load of Different Values of c.

are susceptible to rearrangement of order so that work on a temporarily overloaded machine may be deferred.

C. *Service Center*

It is possible that the individual center reacts to the situation by altering the rate at which it provides service; when there is a large backlog of work, the center "works faster" than when the backlog is small or non-existent. An increase in effort on the part of the worker is an obvious source of increase in service rate, but there are many other factors that could contribute. Quality could be compromised. The system supervisor can use indirect labor to assist in some work elements (materials handling, inspection, set-up, tool maintenance) at an overloaded center which the machine operator might perform under ordinary circumstances.

Considering the service center to be a queueing system each of these adjustments can be considered to have one of the following effects:

1. The capacity of the total service center is changed by altering the number of parallel channels that are available to provide service.
2. The arrival rate is made to depend upon the current state of the system.
3. The service rate (in an individual channel) is made to depend upon the current state of the system.

It is the purpose of this article to postulate a queueing model in which the arrival and/or service rate depend upon the current state of the system. The first type of adjustment—change in the number of channels—has received some consideration elsewhere (2). We are currently working on a more general approach to that problem.

A MODEL FOR STATE DEPENDENT SERVICE RATE

Consider the following model for the service rate in a queueing system:

$$\mu_n = n^c\mu$$

where:

- n is the number of units in the system
- μ_n is the mean service rate when there are n units in the system
- $1/\mu$ is the mean "normal" service time—the mean time to service a unit when that unit is the only one in the system
- c is the "pressure coefficient"—a constant that indicates the degree to which the service rate of the system is affected by the system state.

The usual queueing model, in which the service rate is independent of the system state, is the special case where $c = 0$ so that $\mu_n = \mu$ for all n. When $c = 1$ the service rate is directly proportional to the system state—the serv-

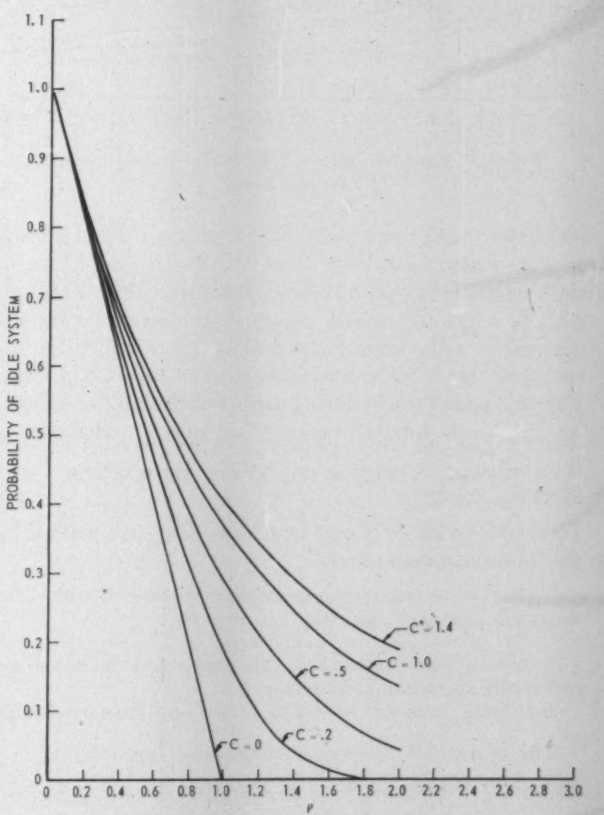

FIGURE 3. Probability of Idle System versus Load for Different Values of c.

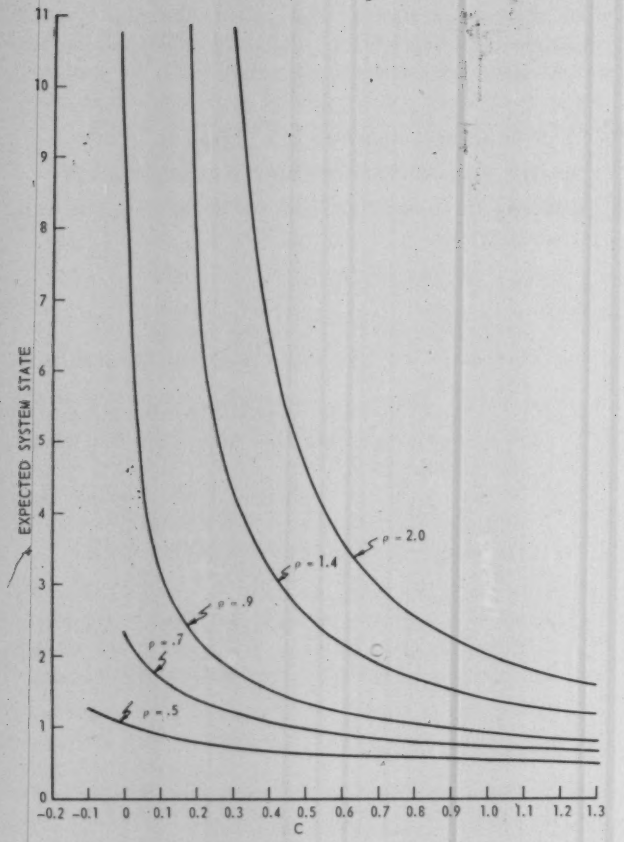

FIGURE 4. Expected System State versus c for Different Values of Load.

ice center works twice as rapidly when there are two units in the system as it does when there is a single unit in the system. One can, of course, consider values less than zero in which the service center slows down as work accumulates, and values greater than one in which the increase in rate is more proportional to an increase in work. Figure 1 shows the resulting service rate at different system states for different values of the pressure coefficient c.

A QUEUEING SYSTEM WITH STATE DEPENDENT SERVICE RATE

Consider a single queue-single server system defined by the following assumptions:

1. The service times are exponentially distributed with mean dependent upon the system state and given by
$$\mu_n = n^c\mu$$
2. Arrivals occur at random; the interarrival times are exponentially distributed with mean λ.
3. Arriving units are served on a first-come-first-served basis.

The system of differential difference equations is:

$$P_0(t+\Delta) = (1-\lambda\Delta)P_0(t) + \mu\Delta P_1(t)$$
$$P_n(t+\Delta) = (1-\lambda\Delta - n^c\mu\Delta)P_n(t) + \lambda\Delta P_{n-1}(t) + [n+1]^c\mu\Delta P_{n+1}(t) \quad \text{for } n = 1, 2, 3, \cdots$$

Transposing and letting $\Delta \to 0$ we obtain

$$P_o'(t) = -\lambda P_o(t) + \mu P_1(t)$$
$$P_n'(t) = -(\lambda + n^c\mu)P_n(t) + \lambda P_{n-1}(t) + (n+1)^c\mu P_{n+1}(t) \quad \text{for } n > 0$$

(Prime denotes derivative)

Assuming a steady state ($Pn'(t) = 0$ for all n), and letting $\rho = \lambda/\mu$ the following equations are obtained:

$$\rho P_0 = P_1$$
$$(\rho + n^c)P_n = \rho P_{n-1} + (n+1)^c P_{n+1} \quad \text{for } n > 0.$$

These equations can be solved recursively in the usual manner:

The first equation—

$$P_1 = \rho P_0$$

From the second equation—

$$(\rho + 1)P_1 = \rho P_0 + 2^c P_2$$
$$P_2 = \frac{\rho^2}{2^c} P_0$$

From the third equation—

$$(\rho + 2^c)P_2 = \rho P_1 + 3^c P_3$$
$$P_3 = \frac{\rho^3}{(2\cdot 3)^c} P_0$$

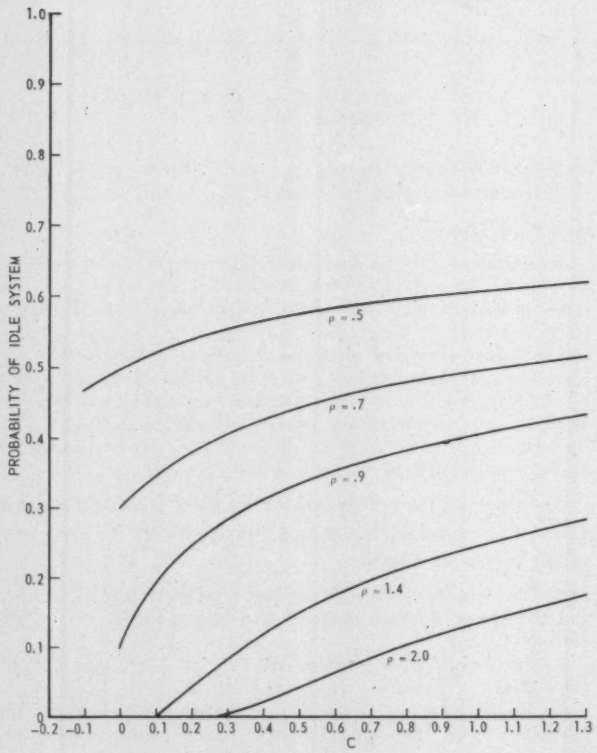

FIGURE 5. Probability of Idle System versus c for Different Levels of Load.

TABLE 1

Top Value is Expected System State. Bottom Value is Probability of Idle System.

Values of C

ρ	−.2	−.1	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0	1.1	1.2	1.3	1.4
0.1	.115	.113	.111	.109	.108	.107	.105	.104	.103	.102	.101	.101	.100	.099	.099	.098	.098
	.898	.899	.900	.901	.901	.902	.902	.903	.903	.904	.904	.905	.905	.905	.905	.906	.906
0.2	.273	.260	.250	.241	.234	.228	.222	.217	.213	.209	.206	.203	.200	.197	.195	.193	.191
	.793	.797	.800	.803	.806	.808	.810	.812	.813	.815	.816	.818	.819	.820	.821	.822	.823
0.3	.510	.462	.429	.403	.383	.366	.352	.340	.330	.321	.313	.306	.300	.294	.289	.285	.281
	.681	.692	.700	.707	.713	.718	.723	.726	.730	.733	.736	.739	.741	.743	.745	.747	.748
0.4	*	.761	.667	.604	.559	.524	.496	.473	.454	.437	.423	.411	.400	.390	.382	.374	.367
	*	.583	.600	.613	.624	.633	.640	.647	.653	.658	.663	.667	.670	.674	.677	.680	.682
0.5	*	1.262	1.000	.861	.771	.706	.656	.617	.585	.559	.536	.517	.500	.485	.472	.461	.450
	*	.469	.500	.522	.539	.552	.563	.573	.582	.589	.596	.601	.607	.611	.615	.619	.623
0.6	*	*	1.500	1.196	1.027	.915	.834	.773	.724	.685	.652	.624	.600	.579	.561	.545	.531
	*	*	.400	.434	.458	.477	.492	.505	.517	.526	.535	.542	.549	.555	.560	.565	.570
0.7	*	*	2.333	1.648	1.340	1.156	1.032	.941	.871	.815	.770	.732	.700	.672	.649	.628	.609
	*	*	.300	.349	.382	.407	.427	.443	.457	.469	.479	.488	.497	.504	.510	.516	.522
0.8	*	*	4.000	2.279	1.727	1.436	1.251	1.122	1.026	.951	.891	.841	.800	.765	.735	.708	.685
	*	*	.200	.270	.312	.343	.367	.386	.403	.417	.429	.440	.449	.458	.466	.472	.479
0.9	*	*	9.000	3.200	2.211	1.760	1.495	1.317	1.189	1.091	1.014	.952	.900	.856	.819	.787	.759
	*	*	.100	.196	.248	.284	.312	.335	.354	.370	.384	.396	.407	.416	.425	.433	.440
1.0	*	*	*	4.619	2.822	2.138	1.765	1.527	1.360	1.236	1.140	1.063	1.000	.947	.903	.864	.831
	*	*	*	.131	.190	.232	.263	.288	.309	.327	.343	.356	.368	.379	.388	.397	.404
1.1	*	*	*	6.947	3.602	2.576	2.063	1.751	1.540	1.386	1.268	1.175	1.100	1.038	.985	.940	.901
	*	*	*	.076	.140	.185	.219	.247	.269	.289	.305	.320	.333	.344	.355	.364	.372
1.2	*	*	*	11.045	4.606	3.086	2.394	1.992	1.728	1.540	1.399	1.288	1.200	1.127	1.066	1.015	.970
	*	*	*	.036	.099	.145	.181	.210	.234	.254	.272	.288	.301	.313	.324	.334	.343
1.3	*	*	*	18.739	5.907	3.680	2.758	2.249	1.925	1.699	1.531	1.403	1.300	1.216	1.147	1.088	1.039
	*	*	*	.011	.065	.110	.147	.177	.202	.223	.242	.258	.273	.285	.297	.307	.317
1.4	*	*	*	33.685	7.600	4.369	3.159	2.524	2.130	1.862	1.666	1.517	1.400	1.305	1.226	1.160	1.104
	*	*	*	.002	.040	.082	.118	.148	.174	.196	.215	.232	.247	.260	.272	.283	.293
1.5	*	*	*	62.262	9.804	5.168	3.599	2.815	2.345	2.030	1.804	1.633	1.500	1.393	1.305	1.231	1.169
	*	*	*	.000	.022	.059	.094	.123	.149	.171	.191	.208	.223	.237	.249	.260	.271
1.6	*	*	*	114.493	12.659	6.091	4.081	3.125	2.568	2.202	1.943	1.750	1.600	1.480	1.383	1.301	1.232
	*	*	*	.000	.011	.041	.073	.102	.127	.149	.169	.186	.202	.216	.229	.240	.250
1.7	*	*	*	206.122	16.326	7.152	4.608	3.454	2.800	2.378	2.084	1.867	1.700	1.567	1.460	1.370	1.295
	*	*	*	.000	.004	.028	.056	.084	.108	.130	.150	.167	.183	.197	.210	.221	.232
1.8	*	*	*	361.557	20.983	8.368	5.181	3.801	3.040	2.559	2.228	1.985	1.800	1.654	1.536	1.438	1.356
	*	*	*	.000	.002	.018	.043	.068	.092	.113	.132	.150	.165	.180	.192	.204	.215
1.9	*	*	*	617.613	26.820	9.752	5.803	4.168	3.290	2.744	2.373	2.104	1.900	1.740	1.611	1.506	1.417
	*	*	*	.000	.000	.011	.032	.055	.077	.098	.117	.134	.150	.164	.177	.189	.199
2.0	*	*	*	1196.543	34.040	11.320	6.476	4.554	3.548	2.933	2.520	2.223	2.000	1.826	1.686	1.572	1.477
	*	*	*	.000	.000	.006	.023	.044	.065	.085	.103	.120	.135	.150	.162	.174	.185

* Indicates value is out of range of the computing formula used.

From these equations for P_1, P_2 and P_3 one can deduce that the general solution might be of the form

$$P_n = \frac{\rho^n}{(n!)^c} P_0 \qquad \text{for } n \geqq 0$$

and substitution of this expression in the general steady state equations verifies that this is in fact the form of the general solution.

To obtain P_o the state probabilities are summed:

$$\sum_{n=0}^{\infty} P_n = 1$$

$$P_0 \sum_{x=0}^{\infty} \frac{\rho^n}{(x!)^c} = 1$$

$$P_0 = \frac{1}{\sum_{x=0}^{\infty} \frac{\rho^n}{(n!)^c}}$$

The mean number in the system, L, is:

$$L = \sum_{n=0}^{\infty} nP_n = P_0 \sum_{n=0}^{\infty} n \frac{\rho^n}{(n!)^c} = \frac{\sum_{n=0}^{\infty} \frac{n\rho^n}{(n!)^c}}{\sum_{n=0}^{\infty} \frac{\rho^n}{(n!)^c}}$$

For two special cases we can substitute for the summations and give analytical results:

Case 1

$$c = 0 \quad \text{and} \quad \rho < 1$$

$$P_0 = 1 - \rho$$

$$L = \frac{\rho}{1 - \rho}$$

Case 2

$$c = 1$$

$$P_0 = e^{-\rho}$$

$$L = \rho$$

For other cases the values of P_o and L can be obtained numerically. Table 1 gives values of P_o and L for different combinations of c and ρ. Figures 2 through 5 are plots of these same data to illustrate the relationships between the variables.

A MODEL WITH STATE DEPENDENT ARRIVAL RATE

A similar model can be postulated in which the arrival rate depends upon the state of the system.

$$\lambda_n = (n + 1)^{-b}\lambda$$

Under the assumption of exponentially distributed service times and interarrival intervals the performance of such a system with $b = \alpha$ is identically the same as that of the previously described model with state dependent service rate with $c = \alpha$. This means that the previously tabulated and plotted results for the state dependent service rate case also apply directly to the state dependent arrival rate case.

A MODEL WITH STATE DEPENDENT ARRIVAL AND SERVICE RATES

A more general model can be given in which both the arrival rate and the service rate are state dependent:

$$\lambda_n = (n + 1)^{-b}\lambda$$

$$\mu_n = n^c\mu$$

Under the assumption of exponentially distributed service times and interarrival intervals the performance of such a system with $(b + c) = \alpha$ is identically the same as that of the state dependent service rate case with $c = \alpha$. This means that the previously tabulated and plotted results for the state dependent service rate case can also be applied directly. It also means that the state dependent service rate case is just the special case of this more general model in which $b = 0$. Similarly the state dependent arrival rate case is just the special case in which $c = 0$.

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CHANGES

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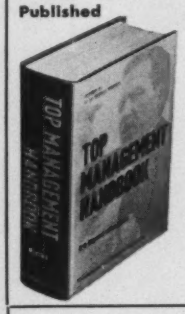

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This article written by Dr. Lillian Gilbreth gives us an insight into Mr. Gantt as an individual, which has so often been lost in the writings about Mr. Gantt's work.
—L. G. TABER, *Chairman, Gantt Centennial Committee.*

As I Remember Him

by **LILLIAN M. GILBRETH**

OF ALL the people of the Scientific Management group, Frank and I felt closest to Henry Gantt and his wife, Mary. We had met them at ASME meetings, and found them most congenial. When we decided to move from Providence, Rhode Island to New Jersey, we selected Montclair as our home town, not only because it was near New York and it was beautiful and it had a fine library and schools, but because the Gantts lived there.

I can remember moving our large family into 68 Eagle Rock Way and having "Father," as everyone called Henry Gantt, coming in on a Sunday morning and sitting on a packing box while Frank sat on another. I tried to unpack and listen to their talk at the same time. And I can remember his insisting that Mary expected us for a peaceful supper, after our children and their Peggy had been settled for the night.

We all four enjoyed chats by their fireplace. Mary, dark, gracious, quiet, spoke little but what she said meant a great deal. Father was more talkative, shrewd and humorous on the surface, but with a feeling not only for the technical side of Scientific Management, but for human values.

He helped Frank and me a great deal, for he knew just how to plan and submit a paper to the ASME, how to present it at a meeting and invite and stimulate worthwhile discussion. He and Frank had high ideals for the future of Scientific Management, enjoyed comparing their experiences, plans and goals. We all four had a "concern" for people that drew us close together.

I always remember an opportunity I had to ask Mr. Frederick W. Taylor, Father and Frank, separately, the same question. This was, "What do you do when you start a new job?"

Mr. Taylor said, "Tell them what needs to be done." "What if they don't want to do it?" asked I. He answered, "Leave them. There are plenty of other people who *will* do what I advise."

Father said, "Ask them what seems to be wrong—try to help them remedy it; go on asking 'What else?' and help again. Finally, they always say 'What do *you* think? We hired you to tell us what is wrong and how to make it right'."

Frank said, "Ask if I can select a job that looks as if it could be improved, and make a demonstration to be sure that everyone knows *what* we hope to do and *how* and *why* we hope to do it before we start to suggest changes."

Each of these three men was a teacher, in his own way. Mr. Taylor a dedicated scientist; Father with fine teaching experience—a master of getting participation even at the beginning of a project; Frank an eager proponent of practicing what you preached and demonstrating that "first he wrought and afterwards he taught."

As the centenary of Gantt's birth is celebrated, I feel that he would be pleased that Scientific Management uses, endorses and includes for its development so many of his ideals and that devoted people, like Wallace Clark and David Porter who worked with him, developed his ideas into adaptable and wide-spread application and incorporated them into teaching both in universities and colleges, in the "life-long learning" and in projects that have spread all over this country and abroad.

We have found the Gantt chart useful whenever work is to be planned—on the farm, in the home, the library, the hospitals as well as in industry and business—and also in planning one's own schedule. The simplicity, practicability, and effectiveness of this technique is a joy to everyone who uses it.

Mr. Alford's fine, carefully written biography has brought Henry Laurence Gantt close to many who would not otherwise have known him. So has Colonel Lyndell Urwick's account of him, in the Golden Book of Management.

Mr. Gantt was a devoted friend, husband and father—I hope I have succeeded in expressing this to others.

Professor Porter, who had the distinction of working with Mr. Gantt, recalls for the readers of the Journal *some of the basic principles which Mr. Gantt instilled in his own engineers.*—L. G. TABER, *Chairman, Gantt Centennial Committee.*

Henry Laurence Gantt—My Boss

by **DAVID B. PORTER**

MY REMINISCENCES of Henry L. Gantt date from World War I when I was working at Frankford Arsenal under his direction, and later as a member of his staff until his death in November 1919.

He was consultant to General William Crozier, Chief of Ordnance, and to the Shipping Board and its subsidiary, the Emergency Fleet Corporation. It was while he was serving these organizations that he developed the progress chart about which Wallace Clark, writing in 1922, said, "The Gantt Chart is the most notable contribution to the art of management made in this generation." An important contribution to the war effort was the application of this chart to the control of imports and exports, and the dispatching of ships to implement this control, which relieved a most critical situation. At Frankford Arsenal, it was used to schedule and show the progress of production on all the details of artillery and small arms ammunition. At Washington, General Crozier extended its use throughout the Ordnance Department until a majority of the activities of the department were shown in chart form so that progress, or lack of progress, could be easily seen. Gantt has stated in his book, *Organizing for Work* that, "No other government department had at that time so clear a picture of its problem and the progress being made in handling it."

In addition to the progress chart the system of Gantt Charts comprised a number of different types for specific purposes, such as the machine layout chart for assigning work to machines in a job shop, the machine record chart which showed the causes and degree of idleness and the man record chart which showed the operator performance against a standard.

Mr. Gantt recognized that these charts were more than tools to aid in production planning and control. They became effective measures of performance of those at all levels from workman to manager. The record is clear and the responsibilities for either good or bad performance are accurately placed. This is a truly democratizing force which causes control to gravitate from weak to strong hands, or as he put it, "to those who know what to do and how to do it." This reflects the philosophy of Gantt who was impatient with any system which covered up the shortcomings of a management and caused frustration and ill-will within the organization.

I have stressed the applications of the charts because during our association I was working mainly with them. However, later I used his method for setting production standards as a basis for his wage incentive system, known as task and bonus, and installed his cost system. This involved the distribution of burden or overhead to the product through the medium of the "machine rate" which made possible the charging to product only the cost allocated to those machines that worked on the product. The idle machine cost was charged to profit and loss. He was the champion of the theory, which was revolutionary at the time, that idle capital (idle machines) was no more entitled to reward than idle labor.

One of Gantt's principles in stores keeping was that the amount of material which represented the "order point" should be set aside physically so that a stores keeper would know when a diminishing supply of stores reached that point, he should make out a requisition for replacement. Under this system to run out of any item of stores was just unthinkable. An amusing incident happened when I was visiting in the Gantt home over a weekend. At Sunday morning breakfast there was a pause after the cereal had been served, and then an exchange of a word or two between Mr. and Mrs. Gantt. Yes, there were no eggs. He turned to me and said, "Don't ever try efficiency in the home." I have found that to be good advice if the efficiency is attempted single handed, but when done in partnership there is no end to improvement.

It was a rich and rewarding experience to have been associated with Mr. Gantt, especially so in the early and formative years of my career. I owe to him so very much. His was a dynamic and forceful personality. He worked hard and was unsparing of self, and expected full performance of those who worked with him. He was direct and to the point with criticism, and equally generous with praise. By his own example of forthrightness he won the esteem and loyalty of those associated with him.

Summary of the Industrial Engineering Symposium, Northwestern University, November, 1959

Reported by **AUSTIN WESTON**

Secretary, Long Range Planning Committee

THE planned program for this Symposium (the fifth sponsored by the Long Range Planning Committee) centered on a discussion of two presentations:

1. The Relation of Industrial Engineering to Management—*Alex Rathe*

2. The Requisite Skills of the Industrial Engineer—*Hal Davidson*

However, after the first day the group felt it was plowing old ground in these discussions—that there was some general agreement on what the modern Industrial Engineer was and what Industrial Engineering can do for management. The group did feel, however, that there was no significant progress in getting the real message of Industrial Engineering over to the management world.

In other words, the Symposium participants concluded that the *Image* of Industrial Engineering, both as a profession and particularly as an organizational function, is very much in need of improvement. Industrial Engineering, as a growing, thriving function, is in danger unless a positive, comprehensive public relations program is developed.

Perhaps this feeling can best be illustrated by citing two questions that were raised:

1. When, if ever, has a magazine like *Harvard Business Review, Business Week, Fortune,* or any other management oriented magazine carried an article on "How Company X Uses Industrial Engineering," or on "Industrial Engineering is contributing to the success of our company by being given these management missions to perform?"

2. How many companies have set up Industrial Engineering departments along the lines of United Air Lines or Procter and Gamble? If such functions aren't being created regularly, it is possible that the success of Industrial Engineering in these companies is largely unknown.

It was felt that Industrial Engineering may well be at a critical point in its desire to be recognized as a designer of systems of management. Without its proper share of managements' attention, Industrial Engineering may lose out in this area to more communicative groups.

A DETAILED LOOK AT THE IMAGE OF THE INDUSTRIAL ENGINEER

Having discarded the original program in favor of this more critical topic, the group then examined the current image of the Industrial Engineer in three areas.

IMAGE AT ACADEMIC LEVEL

The Image of the Industrial Engineer at the academic level is satisfactory. The progress which has been made in designing curricula that prepare the Industrial Engineer for the kind of problems he will encounter 10 to 15 years after graduation is most satisfactory. There is no real problem here. Rather, a problem will exist in providing satisfactory job opportunities for the graduates of these schools.

IMAGE AS DEVELOPED IN THE JOURNAL

The *Journal,* in its editorial policy and content, is making Industrial Engineering acceptable in the modern, technical engineering world. However, again here it appears that articles that can be used to influence management—Industrial Engineering's primary customer—should be published. The *Journal* is urged to continue to generate and publish this type of material. Perhaps an additional periodical slanted toward management should be given study.

THE IMAGE CREATED BY AIIE PROFESSIONAL RELATIONS PROGRAM

The program in professional relations is exemplary—we are now a respected *working* member of the engineering family. Little more needs to be said in this regard except to reinforce the thought that a program in public relations, directed at getting the image properly conveyed to the management world that is as successful as the professional relations program, is urgently needed.

A RESOLUTION

The symposium prepared a resolution and some recommendations to AIIE for its consideration in focusing its management effort:

The Northwestern Symposium on Industrial Engineering expressed concern over the Image of Industrial Engineering, both as a profession and particularly as an organizational function in the minds of Industrial Engineers, other engineers and management. Past symposia have recognized and reported on the concept of the "Modern Industrial Engineer" as the designer of "systems" of management and have outlined opportunities for the "emerging role of Industrial Engineering."

It is the opinion of the Northwestern Symposium that this Image, or *any* image, is not being communicated adequately to the management world in particular. This problem is of sufficient importance that a program of comprehensive scope be developed and promulgated as quickly as possible. This program should be of a long range and continuing nature, directed toward creating an awareness and understanding of the modern Industrial Engineer and the Industrial Engineering Function. The following specific recommendations are offered as guide lines in structuring the program. These are broken down roughly into Public Relations and Professional Development items.

PUBLIC RELATIONS

1. Develop and place definitive articles (case histories) describing the successes of Industrial Engineering in leading management periodicals such as *Harvard Business Review, Fortune, Business Week*, etc. Articles by presidents and vice presidents of such companies as Argus, United Air Lines, Kodak, Procter and Gamble, International Minerals, etc., are illustrative of what is meant.

2. Study the desirability of having a 50th Anniversary celebration of the Amos Tuck Conference on Management or Gantt's 100th birthday in 1961 as a means of showing the modern Industrial Engineer. If desirable, an early start is recommended to allow time to build an effective program.

3. Exercise more national control over the *content* of national convention programs. This should take the form of specific delegation of authority and responsibility to an appropriate national officer or employee. The executive secretary should have some responsibilities in this area.

4. Explore the possibility of two annual national meetings. AIIE has not had a national meeting in or around Chicago or New York in several years.

5. Direct Industrial Engineering publications toward the management world. There are many forms this can take. The Editor of the *Journal* should develop plans in this direction.

6. The AIIE executive secretary can be quite influential in regard to an effective public relations program. He should be aware of public relations methods and experienced in how to develop effective programs.

7. Set up a study group to explore the criteria for defining the proper (and AIIE recommended) use of Industrial Engineering as an organizational function. This is a most difficult subject to explore. On the other hand, encouragement of the proper use of the term organizationally will enhance the image.

PROFESSIONAL DEVELOPMENT

1. AIIE should direct its attention toward the developing, identifying and promoting of Industrial Engineering in terms of the individual professional engineer. In the long run, Industrial Engineering depends upon successful *individual Industrial Engineers* for its success.

2. Develop programs illustrating the professional Industrial Engineer at the chapter level. Develop workshops for Chief Industrial Engineers; build on their strength.

3. Focus attention on the individual as a problem-solver for management problems in the planning, review and control areas of management.

4. Bring the work of other professions in the management area to the professional attention of Industrial Engineers.

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RESEARCH INFORMATION

Once a year the Research Information Committee of the American Institute of Industrial Engineers requests that research sources submit research performed in the area of Industrial Engineering. Sources from which information will be solicited are universities, industrial organizations, research institutions, and non-profit organizations, including government agencies and professional societies. These research abstracts are published annually and provide a valuable service to both industry and universities. Research abstracts are to be collected in the areas of: *Work Measurement, Methods, Plant Engineering, Human Engineering, Engineering Economics, Organization Planning, Industrial Statistics, Production Control, Data Processing, Operations Research, Cost Analysis and Industrial Engineering Education.*

The committee will appreciate all information on Industrial Engineering research past and present, about which it might gather abstracts. Write: Dr. Jay Goldman, Chairman, Research Information Committee, AIIE, Department of Industrial Engineering, Washington University, St. Louis 5, Missouri.

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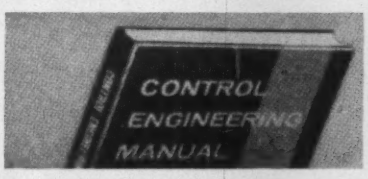

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READER COMMENTS

APPLIED RESEARCH COFFEE TALK, Syracuse Chapter 13, September 13, 1960.

Subject: "Obsolescence and Economic Lot Size," in the September-October, 1959, *Journal of Industrial Engineering,* by R. C. Grassi of the University of California at Berkeley and A. J. Gradwohl, Logistics Analyst at General Electric in Santa Barbara, California.

The selection of a lot size is a compromise established as a result of *setup costs* per unit which are reduced from a maximum figure at a quantity of one to zero at infinity, and the *inventory costs* which start at zero and increase lineally as the lot size increases. As these two costs per unit are added together and plotted against the lot size, their total gradually decreases until it reaches the *economic lot size* and then increases gradually as the inventory cost goes up (Figure 1).

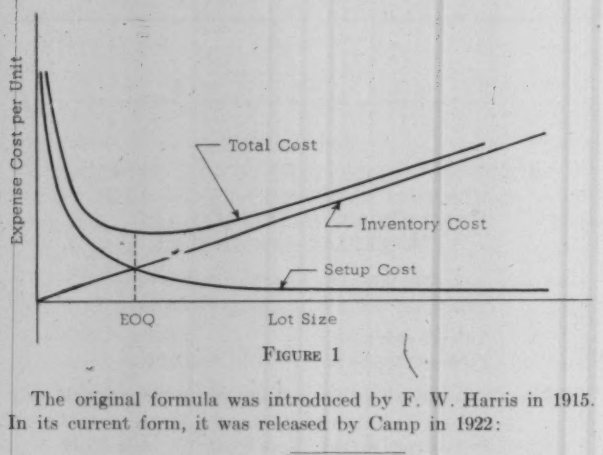

FIGURE 1

The original formula was introduced by F. W. Harris in 1915. In its current form, it was released by Camp in 1922:

$$Q_e = \sqrt{2 \times \frac{R}{I} \times \frac{S}{C}},$$

where Q_e equals the optimum or economical lot size, S equals the setup cost per lot including labor and burden, and C equals the unit cost less setup including material, labor and burden. I equals inventory rate.

This is not a complicated formula to use, so why is it not in more general use today? Although it is still theoretically sound in principle, its use has permitted it to increase inventories to a point where they are too high for practical consideration.

Three ways have been introduced to try to offset this discrepancy:

1. More complicated formulas have been derived in order to bring in more variables and try to offset discrepancies. These have been too expensive to use even with computers, and results have not been satisfying.

2. Since the theoretical minimum of the total cost is where the curve reaches a zero slope, an attempt has been made by some users of the formula to use the point where the curve has a five per cent negative slope. This is more difficult to apply and even harder to understand why it should be considered a true value.

3. An attempt is being made currently to reduce the economic lot size by justifying and using a larger inventory rate (I). A typical breakdown of the inventory rate is:

Interest	.06
Deterioration	.03
Inventory	.02
Handling	.03
Storage and Rent	.02
Obsolescence	.04
Total (I)	.20

Similar figures can be obtained from many authorities and text books which were issued in 1959 on the subject of inventory control.

The last item, obsolescence, as considered by Grassi and Gradwohl in this article is simply a measure of the effect of product change on the inventory. To summarize, without going into the mathematics which are thoroughly explained in the article itself, the obsolescence rate is the reciprocal of the part life measured in years for the average life between changes. As an example, if the average life of the typical product is found to be two years, the obsolescence rate would be ½ or .50.

If we return again to the typical obsolescence of 1959 which was 4%, we find that this represents an average life between changes of 100/4 or twenty-five years, which is certainly not realistic for current normal manufacturing practice.

Using a two-year average life, the inventory rate totals to .66 and the formula for economic order quantity:

$$Q_e = \sqrt{3 \times R \times \frac{S}{C}}.$$

Where the average life is three years,

$$Q_e = \sqrt{\times 4 \times R \times \frac{S}{C}}$$

and the inventory rate is .50.

After six months' experience with this principle, it has been found that it is possible and very practical to save an average of fifty dollars per part, per year, by using this principle. Nevertheless, until this has been tried out and proven by actual experiment, such inventory rates as these should be used only in this index and should not be considered in any accounting or financial calculations.

This is the first of a series of such discussions given on a volunteer basis. They are planned to show practical applications of Industrial Engineering theories, especially, but not exclusively, those published in the Journal of Industrial Engineering.

If you have a pet subject to present for discussion (5-10 minute presentation and 5 minute discussion), please notify one of the Syracuse chapter officers or a committee member for scheduling. —APPLIED RESEARCH COMMITTEE, Millard R. Ames, Chairman, Hobart Eades, Michael Sadlon, Paul Fordyce.

APPLICATION OF DYNAMIC PROGRAMMING TO A CLASS OF PROBLEMS IN INVENTORY CONTROL, by Arjan Bhatia and Anand Garg, *Journal of Industrial Engineering,* November-December, 1960.

The following corrections need to be made in our article:

1. After Equation 2, the sentence should read, "and the cost function Z is minimized where" in the place of, "and the cost function 2 is minimized where."

2. Table 2, last row, last column should read "45" in place of "55."—*Arjan Bhatia and Anand Garg, Engineering Computing and Analysis Staff, Transport Division, Boeing Airplane Company.*

CROSS CHARTING TECHNIQUE AS A BASIS FOR PLANT LAYOUT, by Marshall Schneider, *Journal of Industrial Engineering,* November-December, 1960.

In order that the readers may be able to follow the article with a greater degree of clarity, I would suggest that the following corrections be made:

Under Method 1, Paragraph D, the last sentence should read, "In addition to these, a 'From' column is headed 'Receiving' and a 'To' column is headed 'Shipping.' These represent the areas where the material first enters the department under study and where it leaves the department after the last operation."

Under Method 1, Paragraph E, both instances, Work Center 7 should be changed to Work Center 4.

On the Summary Sheet, Figure 3, in Flow Sequence Number 1, Work Center 3, change the 5 in the circle to 3.

In the Block Diagram, Figure 7, change the 2 products going from Receiving to Work Center 4 to 4 products and likewise change the 2 products processed at Work Center 4 to 4.

When these corrections are made, the figures and descriptive material will be compatible and readily followed.

I would like, also, to emphasize that a Cross Chart will not give the layout. It is merely a decision-making tool which when properly used will aid in providing a sound basis for the most optimum layout.—*Marshall Schneider, Administrative Assistant to the President, Charles D. Burnes Company, Boston.*

Contributed Research Papers for the Twelfth Annual National Conference

A session at the Twelfth Annual National Conference of the American Institute of Industrial Engineers, in Detroit, Michigan, on May 11 and 12, 1961, will be open for contributed papers by individuals doing research in the area.

Titles and abstracts of these papers must reach Andrew Schultz, Jr., Upson Hall, Cornell University, Ithaca, New York, by April 15, 1961. The title should include: title of paper, full name and initial of the author, his affiliation and address. The abstract should be carefully prepared to indicate the essence of the paper, the purpose, what was done, and the conclusion; and it should be limited to two hundred words, double spaced, with one carbon.

It is hoped that the membership will take advantage of this opportunity to report on research accomplishments.

☆ ☆ ☆ ☆ ☆

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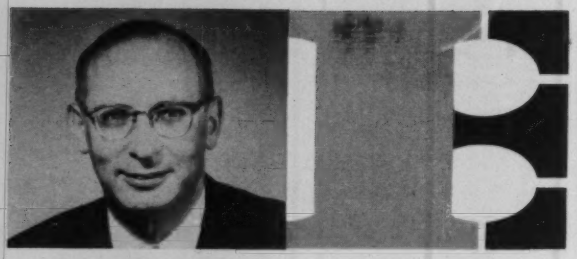

PRESIDENT'S COMMENTS . . .

by **ALEX W. RATHE**

President of the American Institute of Industrial Engineers, 1960-61

Industrial Engineering and Science

Part I—Research: Blueprint for Progress

THE two preceding issues discussed Industrial Engineering Contributions to Managerial Planning and Control.[1] I stressed the service character which planning and control (or review) have with regard to the crucial third component of the management cycle, operations; its task —to obtain the desired results in whatever activity it may be engaged—is the all-encompassing mission of management.

MANAGEMENT RESEARCH AND DEVELOPMENT

Surrounding operations in terms of time, planning and control facilitate the accomplishments of these results. A model of management could therefore be drawn as in Figure 1.

The purpose of planning is to look ahead. It determines what *ends* (objectives, goals, programs, etc.) should be pursued; and it develops the *means* (organization, policies, procedures, standards, etc.) by which the existing resources can best be arranged to produce the desired results.

The task of control is to look back. It records what *effects* were generated in operations (by measuring cost, quantity, quality, satisfaction and other key criteria of actual performance); and it dissects these finding to dig through to the *causes* which produced them. Feedback joins the three elements of the managerial task together, forming a cycle or a closed loop (without, though, the feature of automatic error correction).

Problems appear in both sectors. Planning is concerned with all existing and potential obstacles which proper advance preparations could mitigate or overcome completely. Control comes to grips with all questions which are appearing when observing operations. Answers must be found for all these issues before future planning can avoid their repetition if their nature is unfavorable, or assure their recurrence if their consequences are desirable.

In some instances, planning or control work can crack these problems. In others, this is either impractical or impossible, too time-consuming or too costly. Unresolved matters can therefore readily accumulate. Especially if they have predominantly unfavorable consequences, a "wait-and-see" attitude makes their ultimate conquest progressively more difficult. The problem then becomes what to do with those problems whose solution is not readily forthcoming.

The answer is "research"—applied to managerial issues, just as research has long been used to find explanations and remedies for difficulties in other areas.

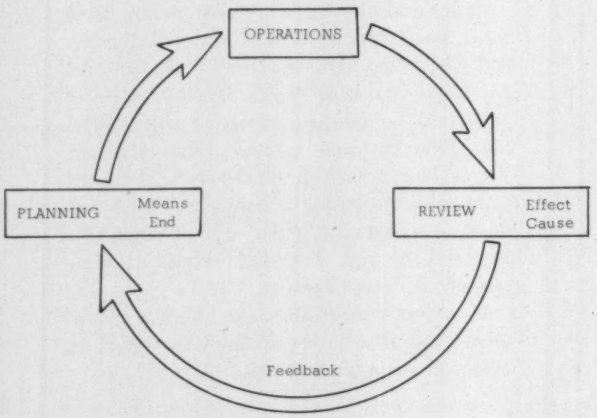

FIGURE 1. The Management Cycle.

[1] Comments upon the preceding articles in this series have been such as to suggest the expansion of the space originally allocated for the discussion of Research. This article is therefore again written as the first of a sequence of two; it looks upon Research and Industrial Engineering from a general point of view. Its companion ("The Industrial Engineer and Management Research" to be published in the May-June, 1961 issue of the *Journal*) will take up more specific details.

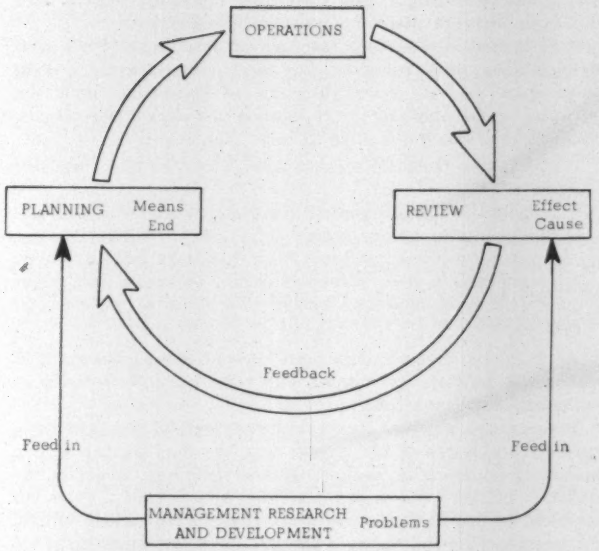

FIGURE 2. A Management Model.

But there is at least one other major reason for management to consider taking recourse to research. The very nature of a closed loop such as the management cycle limits its access to information; it is dependent upon the intelligence which it generates itself. Feed*back* (of conclusions from review into planning) makes our own past experience available for future action.

However data generated within a system must be supplemented from without. Such feed*in* avoids the danger of in-breeding. It prevents the hazards of operating in ignorance of factors outside the system which are, nevertheless, likely to exercise their influence inside, too.

For example, figures on cost or quality of a firm's operations, is information which flows freely within the management cycle when feedback functions effectively. But information on available markets and their purchasing power, or on impending union or legislative developments, exists only outside the confines of the system. It must be fed in, promptly and undistortedly, if planning is to proceed in awareness of all significant factors which affect operations. Again research—now used in its less-strict sense and thus perhaps better termed "development"—is the means by which the executive can assure himself of all needed information.

Combining both of these opportunities for Research under the term "Management Research and Development," we can now draw a more complete management model; in its fundamental form (Figure 2).

THE SIXTIES: DEDICATED TO SCIENCE

Industrial Engineering is of course vitally concerned with Management Research and Development. It helps solve many of the existing planning and control problems with which the Industrial Engineer has been occupied; and it contributes to the development of new alternates or new solutions; it could create entirely fresh knowledge.

But research is the domain of science. It is an activity in which engineers have served often and with distinction although such work does not constitute "engineering" in its narrowest sense.

It has, unfortunately, also been an endeavor in which not just contemporary practice has at times abused the venerable name of science to produce results whose value is as questionable as its origin is unscientific.

No progressive firm would think of marketing its products (or services, whichever the case may be) these days without vesting their design with the strength which bona fide research and development can bestow. Product research and development has a fully accepted part in the cast of characters on the business scene of today. Although similar advantages can be secured when research and development are employed in solving management problems, management research has not yet been accorded the same firm position as its counterpart in the product arena.

But even the fields in which science and research are now a firm fixture, have enjoyed this situation only in rather recent years or decades. It is just 500 years ago that a few though indeed immortal names—such as Copernicus and Newton, Galileo and Descartes—comprised the full sum total of the contributions of science at that time. The roster grew gradually when Dalton and Lavoisier, Hertz and Roentgen, Maxwell and Mendel inscribed their names indelibly upon the eighteenth and nineteenth centuries. With the turn into the twentieth century, the rollcall expanded mightily with such names as Einstein, Rutherford and Curie; Urey, Planck and Bohr; Freud, Fleming and Pavlov. When we look at our contemporaries, we can not even begin to list a small selection from the large assembly of truly great scientists without running out of space.

Recent years have brought in the United States a veritable avalanche of interest in science—on many and diversified fronts. Numerous witnesses could be called to testify to this statement. For example:

> . . . Progressive management has shown a steadily increasing interest in, and understanding of, research.
>
> . . . So has the Federal Government, especially the Armed Forces and the Department of Agriculture. Other non-profit organizations are being formed, seemingly in growing number, to engage in scientific work.
>
> . . . It is therefore not surprising that total "research" expenditures in the country have doubled in the last seven years (to their 1960 record of near the ten billion mark).
>
> . . . Preliminary investigations appear to show rather conclusively that extra volume and profit increases go to the companies who consistently and effectively employ research and development in the task of improving their products.
>
> Thus more and more items, which every one of the 180,000,000 American and the additional millions of our overseas customers buy these days, will serve them better because of the extra values which have been added to their features and performance as a result of intensified research.

It was just fifteen years ago when the first DC-6 flew; it represented research and development and engineering effort of some 750,000 manhours (and sold for $650,000). The DC-8 could make its debut, in 1958, only after an eightfold research and development and engineering investment (of some 6,000,000 manhours, which contributed to the need for raising the price tag to $5,000,000).

. . . Many circles see as one cause for the drop of enrollment in engineering curricula in the past few years the lure which science has been exercising upon youngsters who graduate from high school.

It might not even be out of place to mention a current and widely disseminated advertising series to illustrate the vast change which the image of the scientist is undergoing in the public's mind. This series supports the claims for its products, a cigarette, by stating that it is the favorite choice of the "men in science." When Madison Avenue holds out people who just a few years ago were popularly seen as "eggheads" and "long hair," as an example to the other and much more numerous mortals, science has arrived.

Awareness of the potential of science and of its effects as they become practical and profitable through research and development work in so many areas, is one of the reasons why such enormous changes seem to take place these years—in this country and the world at large, in engineering and just about every other discipline including, very much so, Industrial Engineering.

Before remarks on the specific role of science and research in management and in Industrial Engineering can be practical, two general thoughts must be recorded:

1. Science spawns innovation. And innovation is needed before we can make progress, which is management's ultimate goal. Research brings new thoughts to the surface. It "creates" in the finest sense of the term. It acts as a catalyst for one of man's most unique and precious abilities, creativity.

Every phenomenon of life or technology, every trait of material matter or of a human being holds untold secrets which a Greater Power wisely locked up. It takes the best in us to match our feeble skills against the universe in an attempt to penetrate just one infinitesimal stitch.

But why were we given the right to think and the gift to search if it was not to encourage the use of these faculties—for the purpose of thinking up something useful and new, for the benefit of ourselves and of others.

Similarly a nation's capacity for economically profitable and socially lucrative innovations must be recognized as a national resource of unrivaled power. Many economists believe that the greatest impetus to developments in the United States during the next ten years—if not for much longer—will stem directly from research results which would support and possibly snowball the influence of more customary factors such as population increase, rise in productivity, capital investment and others.

Research develops things which we shall need tomorrow when what we have today won't do anymore—in technology, in medicine or in management. None of us would keep as our family physician a doctor who refuses to utilize the discoveries of medical science which have become available since his graduation from college. A practitioner who, say, ignores the existence of antibiotics, would not be frequented by his patients very long nor tolerated by his profession.

And this applies with equal force to our field. Deliberate research and application of its results is the surest way by which the Industrial Engineer can keep from relegating himself into this same niche of premature personal obsolescence.

2. Unlimited Horizons. As management deals with people and, through them, with just about any matter on earth and now in outer space as well, every discipline of knowledge holds the potential of contributions to the solution of managerial problems. Treasure mines as yet uncovered hide knowledge in every field:

. . . in the technical sector (through physics and chemistry above all),

. . . in the social segment(psychology and sociology, economics and anthropology, etc.),

. . . in the medical world including physiology and psychiatry,

. . . but also in areas whose relationship appears at first rather remote (such as molecular biology, the study of the chemical basis of life).

As Industrial Engineering's orbit covers a sizable spectrum of managerial activity, its concern with these scientific roots is as immediate as it is practical.

Perhaps the absence of the systems-view in our field until recent years, is one of the reasons why we were satisfied with a piecemeal approach in research. Not so long ago, economic research or market research or research on fundamental time values appeared to many of us as isolated endeavors which had nothing in common. Yet in reality, they are interconnected; most of them have common roots in different disciplines; all of them possess the opportunity of sharing reciprocal benefits which a discovery in one field can have on unsolved problems in another.

This magnificent depth of the panorama of scientific knowledge explains only one part of the opportunities which exist for our branch of the profession through research. "For every Galileo or Einstein, with their intuitive explosions of individual genius," *Time* (1) characterized developments recently, "there follow hundreds of other scientists, probing and proving and progressing."

This is one of the most encouraging exhibitions of the phenomenal strength of a free society where work that was courageously begun by just a handful blessed with genius, is expanded and reinforced by hundreds and thousands of ordinary citizens.

The realm of scientific investigation in research is not merely the prerogative of a selected few. It offers opportunities for all whose intellectual curiosity does not let them rest with the discovery of questions as long as their mind can extend itself to the formulation of a partial or even a full answer and as long as their intellectual honesty holds out.

Designing devices or building bridges, piloting planes or doing any other type of work demand special abilities and interests before we can find success and satisfaction in each endeavor. Similarly engaging in research is something for which not everybody is suited.

What may seem to some of us to have little interest and challenge appears to others as the acme of fulfillment. "We scientists are the only people who are not bored, the only adventurers of modern times, the real explorers—the fortunate ones," is the way Dr. Willard F. Libby summed up his views when accepting the Nobel Prize in 1960.

Thus concern with research and development, while as vital for Industrial Engineering as for any other occupation which seeks to acquire the strength needed for ever-farther development, is something to which only a portion of us will ever be attracted. This makes research activity not one iota less significant. On the contrary, it becomes that much more mandatory as too large a proportion of Industrial Engineers is recognizing the necessity for more research and development in our field only in much too recent years or months.

JUST WHO'S FIRING THOSE MISSILES?

When speaking of "research," I have so far not differentiated between "pure" (or "basic") and "applied re-

search" (or "development"). In the former, the purpose is the search for knowledge for knowledge's sake. In the latter, the objective is the utilization of such knowledge in the interest of some other mission.

Disclosures from pure research are to the scientist a fully self-sufficient goal; to him they are an end in themselves. In "applied research" or for the engineer, the findings from pure research are significant mainly to the extent to which they enable him to use them for something else. They are a means toward some other end which is likely to be the improvement of one or several features of an existing product or the creation of an entirely new item.

Without being able to refuel with the knowledge unearthed by pure research, applied research engineers would soon find themselves placed on meager rations. Yet engineering work, as such, is out of bounds in pure research efforts as it is in the operations phase of management. Again this does not mean that engineers have not been highly effective in both areas; but such success was not general; it was won on the strength of special experiences and knowledge beyond engineering.

The relation between engineering and science has changed radically in a few short decades. Years ago, the engineer built machines which worked although science often did not know why. Watt's steam engine and much of the early electronics are two out of a large array of possible examples. Today the situation is reversed. Engineering progress is much more dependent upon scientific discoveries. We need science for new knowledge and new ideas, for the explanation of phenomena. It is the one unimpeachable reference source for facts and their relationships as well as for the safe prediction of results from their interactions.

The demarcation line between pure and applied research—or between science and engineering—is not always readily fixed. It has caused much confusion and even more dismay. "Just Who's Firing Those Missiles?" asked the headline of one of a series of ads which Engineers Joint Council placed a year or so ago in a number of publications. The piece continued:

> From the news stories you might think that Cape Canaveral is populated only by scientists and electronic brains. As a matter of fact, much of the design, construction and operation of our missiles and satellites is the work of engineers.
>
> Engineers don't want to take credit from the scientists upon whose original research the missile program is based. But they do feel that the public should recognize engineering as a major force in the missile program.

I feel as strongly as any engineer that our field is being shortchanged in the reports of many newspapers and magazines, on radio and television.

When (Democratic and Republican) Congressmen debated the question of whether a United States agency should be created to take over most, if not all, the scientific and engineering work currently performed in many different bureaus, they disagreed upon most aspects of the proposal. But none of them raised an objection to the suggested name: "Department of Science and Technology" when "Department of Science and Engineering" would have been much more appropriate.

This situation is our own fault as much as anybody else's. We simply have not recognized as one of our obligations the need for telling the public what we are doing. Industrial Engineers are as guilty in this respect as any branch. This is one of the reasons why such top-priority attention, in the 1960/61 AIIE program and indeed in our longer-range plans, has been assigned to public relations work which is gathering a tremendous head of steam under the dynamic leadership of Nick Olijnek in Minneapolis.

Before we can explain this to others, we have to realize ourselves that scientists and engineers are practitioners of complementary professions. One is dependent upon the other: The engineer needs the researchers because they generate the knowledge he uses; and the scientist needs engineers because they help put his ideas to work—profitably.

Is Industrial Engineering then concerned with operations research? My answer is unequivocally: "Yes—as long as operations research does bona fide research or development work on managerial problems with professional calibre." And our concern does not stop with operations research; any other activity in research whose findings could strengthen Industrial Engineering is an equally welcome companion.

The problem therefore is to find ever more and better ways to facilitate the exchange of ideas between all these fields. The New Industrial Engineer encourages research; it brings him the additional knowledge he requires; and it stands him in good stead whether it is produced by a "management scientist," by an "operations research practitioner," or by a "systems researcher."

How can we convince others of the need for change and of the obligation for never-ceasing progress if we do not apply this maxim to ourselves first. Thus those of us who are equipped with the traits and the knowledge which scientific endeavor demands have another opportunity to advance, through research, the potential of Industrial Engineering and enhance its usefulness ever further in the years to come.

A long time ago, the Belgian Maurice Maeterlinck wrote:

> At every crossway on the road that leads to the future, each progressive spirit is opposed by a thousand men self-appointed to guard the past.

The New Industrial Engineer, far from rutting on such ignominious sentry duty, is one of the designers of the future.

REFERENCE

(1) *Time*, Vol. LXXVII, No. 1, January 2, 1961, p. 41.

RECENT READABLES

AUTOMATION

"A Special Analysis on Computers," J. A. Eaton, MATERIALS HANDLING ENGINEERING, *October 1960.*

A look at computers, their importance and how they are being used to aid in the flow of materials. The various makes and models are presented to aid in the selection of the best computer by a given situation. (*J. P. Fagan—Ethyl Corporation*)

"Tape-Controlled Machine Drills, Reams, Taps, Counterbores," THE IRON AGE, *October 27, 1960.*

Most people think that tape-controlled machine tools aren't adaptable to short work runs. These people are way off base.

At a major jobbing shop, a tape-controlled unit handles prototype parts or short runs.

"Summary of a Heuristic Line Balancing Procedure," Fred M. Tonge, MANAGEMENT SCIENCE, *October 1960.*

This article describes a procedure for solving assembly line balancing problems with the aid of a computer. Stated simply the procedure will give you the smallest number of work stations for a required production rate when each task along with its relation to other tasks and its elemental time per unit are known. (*J. P. Fagan—Ethyl Corporation*)

COST CONTROL

"Value Analysis in Buying Forms, Printing," Harold McDonald, THE OFFICE, *December 1960.*

The application of value analysis to the purchase or use of printed forms is practically unlimited. Some are of a permanent nature, while others are delegated to the wastepaper basket after they have served a single purpose.

"Financial Reporting," by John Coughlan, ADVANCED MANAGEMENT, *November 1960.*

Perhaps the most obvious and important requirement of a good system of financial reporting is that it should relate results to the people who achieve the results. It should relate performance to responsibility.

"Quick Actions Nip High Labor Costs," W. C. Cooling, MILL AND FACTORY, *October 1960.*

Mr. Cooling reviews a sound, practical and effective program for labor cost control. Primary aspects of the program include distribution cost centers, time study standards and training. (*J. M. Barksdale—Ethyl Corporation*)

GENERAL

"Relationships Between Organization Size and Efficiency," F. P. Adler, MANAGEMENT SCIENCE, *October 1960.*

A presentation of the relationships of size, production and efficiency in a technical organization. There is a point where the productivity is independent of the number of employees and an organization size where efficiency falls off inversely proportional to the number of employees. (*J. P. Fagan—Ethyl Corporation*)

"Climate for Creativity," Eugene Raudsepp, MACHINE DESIGN, *July 21, 1960.*

Engineers are a creative lot but often employers divert and suppress this natural bent. Recent studies prescribe a hands off attitude by management. This article gives "do's" and "don'ts" by which management can generate and maintain a climate in which creativity flourishes. (*A. L. Friedrichs—Ethyl Corporation*)

"How to Multiply Your Effectiveness As An Engineer," P. Marvin, MACHINE DESIGN, *October 13, 1960.*

The mantle of success seldom falls over anyone's shoulders. It is achieved by hard work. But effort alone is not what counts; it's effective effort that is important. This article outlines the steps to follow to improve your effectiveness. (*A. L. Friedrichs—Ethyl Corporation*)

"You and the Unions—Part 2," MACHINE DESIGN, *November 24, 1960.*

What the unions are doing to attract engineers and what their plans are for future expansion. (*A. L. Friedrichs—Ethyl Corporation*)

"Facts and Figures Everywhere," Gordon Weyermuller, CHEMICAL PROCESSING, *December 1960.*

As the volume of business and technical reports, correspondence, and publications climb, companies are trying new schemes of information retrieval. Goal: efficient, economical methods of keeping executives and scientists informed of developments bearing on all aspects of company's business.

"Management Rights are Slipping," Editorial Article, ENGINEERING NEWS RECORD, *October 6, 1960.*

The U. S. Supreme Court's "Big Brother" philosophy in recent labor cases constitutes a major assault on management's right to manage says this article. It goes on to point out how unions have been strengthened in their resistance to management's efforts to improve efficiency. Jeopardized rights include the right to eliminate jobs, assign work and to contract work out. Means of protection against or resistance to these encroachments are possible and available to intelligent managements. These are presented and discussed. (*J. M. Barksdale—Ethyl Corporation*)

"Men, Morality and Management," A. M. Sullivan, DUN'S REVIEW AND MODERN INDUSTRY, *October 1960.*

Mr. Sullivan, in a fine change-of-pace article, pulls the eminently important and pertinent question of management morals from the confusion of industrial expediency and makes a constructive and enlightening appraisal of the problem. He professes practical and effective answers to the question "What can the executive do to counter the critics, and define the limits of his own responsibility?" (*J. M. Barksdale—Ethyl Corporation*)

"Maintenance Painting," Kenneth Tator, FACTORY, *December 1960.*

If you are using Class I (the best) coatings on a Class IV (primarily appearance) surface, your paint bill may be four times as much as is necessary for the protection you need. This article gives you a basic guide for selecting the right paint for the job. Also, proper painting practices can lengthen the life and improve the effectiveness of the job. (*J. P. Fagan—Ethyl Corporation*)

INVENTORY CONTROL

"A Note on the Optional Range," Samuel Eilon, MANAGEMENT SCIENCE, *October 1960.*

This is a short presentation of a method for finding the optimum

economics range of production in the case of batch production. (*J. P. Fagan—Ethyl Corporation*)

MATERIALS HANDLING

"New Breakthrough in Underground Warehousing," MATERIALS HANDLING ENGINEERING, *November 1960.*

You may be able to use abandoned limestone and salt mines to give your company additional storage space at a fraction of the cost of conventional storage. The article presents the pros and cons of this style of warehousing. (*J. P. Fagan—Ethyl Corporation*)

"Now—A Way to Measure Materials Handling Performance," G. C. Thomas, MODERN MATERIALS HANDLING, *November 1960.*

A successful method for evaluating materials handling efficiency in any size organization is presented. This basic approach may be used by anyone as a step toward better materials handling. (*J. P. Fagan—Ethyl Corporation*)

OPERATION RESEARCH

"Simulation—Tool for Better Distribution," H. N. Shycon and R. B. Maffei, HARVARD BUSINESS REVIEW, *November-December 1960.*

Not a treatise on theory, but a practical, step-by-step description of how a simulated distribution system was developed and used to help solve many warehousing and marketing problems of a major company. (*A. L. Friedrichs—Ethyl Corporation*)

"A Non-Linear Extension of the Simplex Method," Peter Wegner, MANAGEMENT SCIENCE, *October 1960.*

The article presents a variation of the Operations Research technique known as the simplex method for the solution of programming problems containing non-linear constraints. (*J. P. Fagan—Ethyl Corporation*)

QUALITY CONTROL

"Automation and Quality Control," J. R. King and R. Miller, INDUSTRIAL QUALITY CONTROL, *October 1960.*

Discusses the need for increased productivity, the part that Automation will play in accelerating our progress in this respect and the implications this will have in the field of Quality Control. (*A. L. Friedrichs—Ethyl Corporation*).

"Radioisotopes Broaden Field for Non-Destructive Tests," Robert Hamlin, THE IRON AGE, *December 1, 1960.*

Use of radiography in inspection is growing. But the potential of atomic methods is scarcely scratched. What can the new test techniques do for you?

"What's the Problem in Quality Control?," L. F. Miklon, FACTORY, *December 1960.*

A discussion of Quality Control problems in American industry. Consumers often compare American manufactured goods to imported products and end up buying the foreign product with the idea that it will last longer. Appliance makers, troubled with many Quality Control problems in the past, are coming up with good solutions to these problems and many of them can help to improve quality in other industries. (*J. P. Fagan—Ethyl Corporation*)

SYSTEMS AND PROCEDURES

"Mr. Systems Man: Wear a Tie!," Thomas G. Horti, THE OFFICE, *November 1960.*

The wearing of a hat, jacket or tie is not an expression of rank or badge of office. It is, rather, an expression of formality or correctness. It expresses a recognition of rules of business conduct, of certain protocols which, though unwritten, govern the day-by-day relationships of people in the business world. The systems man, usually a staff advisor, whose work must be accomplished by personal persuasiveness and tactful counseling rather than by the use of direct authority, is especially reliant on these rules of conduct which provide the framework for his activities.

WORK MEASUREMENT

"Industry Studies Job Stresses," G. J. McManus, THE IRON AGE, *November 10, 1960.*

Both science and industry try to discover how the human body acts as a work machine.

Some progress has been made, but more detailed data are still needed.

"How to Improve the Efficiency of Those Who Must Stand at Their Work," Eugene Behrstock, THE OFFICE, *December 1960.*

Management could save money by making personnel who must stand at their work more comfortable. This is the burden of a series of tests carried out with employees in this category. They included machine operators, filing clerks, counter clerks, and many others.

"Work Measurement for Pour and Shakeout," R. S. Casciari, MODERN CASTINGS, *August 1960, page 58.*

This is a discussion of the Industrial Engineering approach to the development of a work measurement plan for a highly varied foundry operation; namely, pour and shakeout. The pour and shakeout operation in the jobbing foundry is nonrepetitive and highly variable. It also has some restrictions which affect the overall time to perform each function in the operation. These factors have long been problems to those who have attempted to measure this type of work. (*I. L. Haines—Lukens Steel Company*)

"Management Tackles Office Productivity," Thomas Kenny and Jos. R. Marshall, DUN'S REVIEW AND MODERN INDUSTRY, *September 1960.*

These experts say there is room for a 50 percent increase in office efficiency. They review what is being done by top executives to improve performance and quality and to reduce cost. (*J. M. Barksdale—Ethyl Corporation*)

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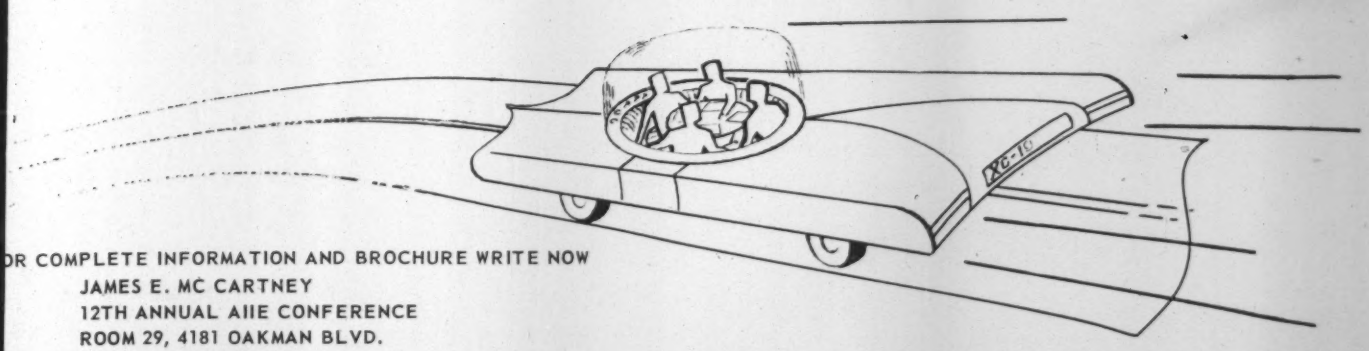

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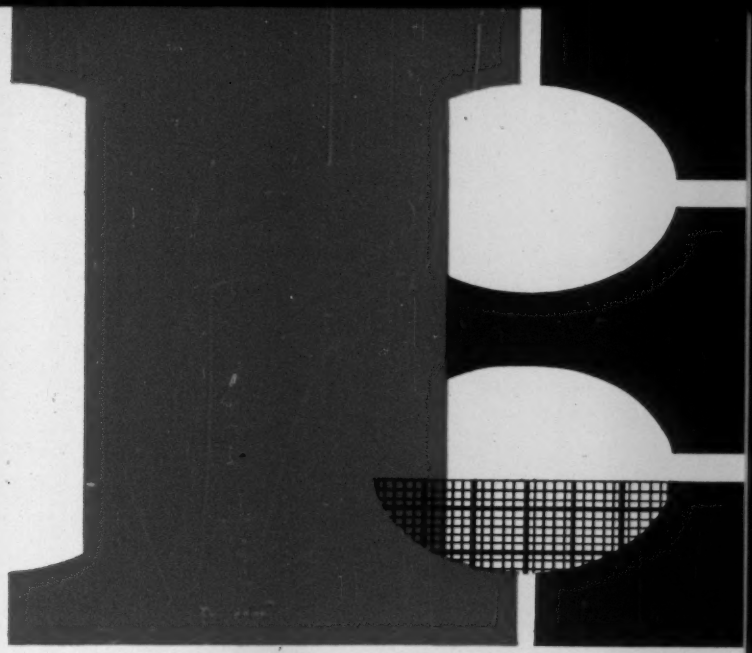

The Journal of **INDUSTRIAL ENGINEERING**

MARCH-APRIL 1961 VOLUME XII NUMBER 2 PART 2

THE EMERGING ROLE OF INDUSTRIAL ENGINEERING

A Summary Report of Industrial Engineering Symposia Sponsored by the American Institute of Industrial Engineers

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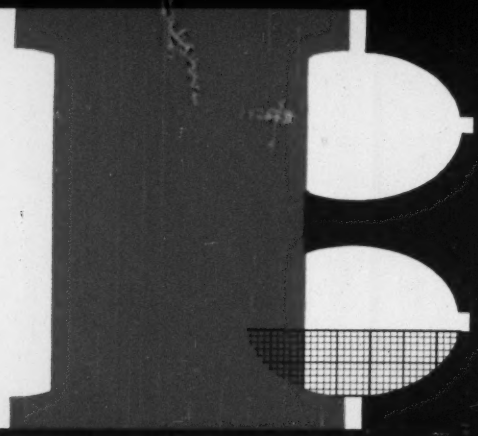

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The Emerging Role of Industrial Engineering

A Summary Report of Industrial Engineering Symposia Sponsored by the American Institute of Industrial Engineers

edited by **AUSTIN WESTON**

Secretary, AIIE Long Range Planning Committee

THE AIIE has grown tremendously since its founding in 1948. This growth has brought many new people into this Institute; it has also increased interest in the Industrial Engineer and his activities in business, government, service organizations and industry by those in management and related professions. As a result many questions have been raised concerning the Industrial Engineer, his duties and responsibilities, his relation to the engineering profession as a whole, his relation to management, and the tools and techniques he uses.

For several years the AIIE Long Range Planning Committee has been sponsoring symposia designed to find answers to such questions—to develop the "image" of the modern Industrial Engineer. The results of these symposia, while published individually over the years, have not heretofore been collected and merged into one account. This report is for the use of practicing Industrial Engineers, to give them a panorama of the changing nature and the widening scope of their profession, and for those in management and other areas who are interested in Industrial Engineering, to reveal to them the emerging role of the Industrial Engineer.

THE SYMPOSIA CONCEPT

The Industrial Engineering Symposia were conceived in early 1955 by two of the country's leading Industrial Engineers, D. G. Malcolm and C. W. Lake, Jr., as a result of discussions of problems facing this new and growing profession. They both felt that something needed to be done to solidify and improve the standards of the profession, and to clarify the functions of Industrial Engineering. This concern led them to invite a number of leaders in Industrial Engineering to a short meeting held during the AIIE National Convention in St. Louis in May of 1955.

At this meeting a number of opinions on the problems facing the Industrial Engineering profession were voiced and remedies for these problems were suggested. The following specific suggestions came out of this meeting:

1. The AIIE should develop a definition of Industrial Engineering consistent with the definition of Engineering.
2. This group should meet again for two days in the fall of that year at Cornell University to explore the subject further.

Thus the stage was set for the first of the symposia.

THE SYMPOSIA OUTPUT

Five Industrial Engineering Symposia have been held since 1955 (see Appendix No. 1 for dates and places). In general these symposia have served to define and explain Industrial Engineering, to illustrate the design process in Industrial Engineering, to emphasize the areas in which the profession can make its greatest contribution, and to explore the tools and techniques used in the Industrial Engineering process. They have developed the concept of the modern Industrial Engineer as the designer of productive and management systems and have outlined opportunities for the emerging role of Industrial Engineering. The participants in the symposia have been leaders in the industrial, academic, consulting and governmental branches of the profession (see Appendix No. 2 for the names).

The remainder of this report is concerned with a summary of the concepts developed in the symposia.

THE DEFINITION OF INDUSTRIAL ENGINEERING

Industrial Engineering is concerned with the design, improvement, and installation of integrated systems of men, materials, and equipment. It draws upon specialized knowledge and skill in the mathematical, physical, and social sciences, together with the principles and methods of engineering analysis and design, to specify, predict and evaluate the results to be obtained from such systems.

This definition was developed by the participants at the first symposium (3). It was intended to reflect the unique character of the Industrial Engineer, and it is sufficiently general to include the diverse areas in which Industrial Engineering can be of use. It was also intended to identify Industrial Engineering as an engineering discipline, and to place it within the scientific framework surrounding all branches of engineering. At the time of its development it was recognized that this definition could and should be improved as the need arose.

This definition was officially endorsed by the AIIE at its annual convention in May, 1956. Since this time it has been widely published and it is one of the best known definitions in the entire engineering field.

AN INTERPRETATION OF THE DEFINITION

The interpretation of this comprehensive definition to both lay and professional groups immediately created a

problem. Therefore, the next symposium was primarily concerned with communication and understanding of this definition (4). It was concluded that most of the other problems facing the profession, such as curricula design, organization and direction of research, proper publicity, and the attractiveness of the profession as a career, could not be properly approached unless the basic mission of the Industrial Engineer was communicated to and understood by all concerned. As a result, the members of the symposium decided that, while the definition need not be changed, it should be expanded and interpreted for specific groups. Four expository paragraphs were developed, each one aimed at explaining what an Industrial Engineer is and what he does. Each of the four paragraphs was written in terms which would mean most to one of the following groups:

1. Management.
2. Employees in Industry.
3. Engineers and Other Staff Groups.
4. General Public (with special emphasis for high school students).

These interpretations were recommended to the AIIE as aids in promoting better understanding of the Industrial Engineering profession. They are presented, not as the last word on this subject, but to provide a basis for future discussion and for use where appropriate.

1. INTERPRETATION FOR MANAGEMENT[1]

The Industrial Engineer makes an engineering contribution to achieving management's objective, primarily that of optimizing the gains and minimizing the risks of an enterprise. He assists every level of management by originating and developing operating plans, programs and controls which will permit the increasingly effective use of human and economic resources.

This is accomplished through stimulating and working with other staff and line departments in such fields as:

—making location and site, layout and handling plans.
—designing organization and operating procedures.
—designing controls for organization functions.
—designing tools and equipment, work processes and methods.
—designing compensation plans.
—determining the most economic way of procurement and use of materials.
—analysis and evaluation of data and other information required for these planning tasks.
—conducting research in these areas.

2. INTERPRETATION FOR EMPLOYEES IN INDUSTRY

The Industrial Engineer is a fellow employee who is concerned with the problem of finding easier ways for you to do your work. He is not your boss, but is merely an advisor to you and your foreman. Obviously he is not as skilled in doing your particular job as you are, but he does have certain special training and experience, especially in the analysis of work. With your knowledge of the job, and his knowledge of ways to analyze and study work situations, he can help you work out an easier way to get your job done. As easier ways to do your job are found, costs will be reduced, and your company will be able to sell your products at a lower price. This will create a greater demand for your products and more jobs.

Not only is the Industrial Engineer interested in improving what you yourself do, but he must be concerned with those things which affect your production, and over which you have no control. The equipment you use, its position in the plant, the building in which you work, the way in which your work is scheduled, and the condition of the work you receive are examples of these factors.

In his role as an advisor to you, your foreman, and other management people, he is continuously looking for further improvements, and therefore is never satisfied with things as they are. He attempts to keep up with the best practices and newest devices in order to make sure your company is always doing every job in the best possible way.

3. INTERPRETATION FOR ENGINEERS AND OTHER STAFF GROUPS

The Industrial Engineering approach is a unique application of engineering design and analysis techniques. The Industrial Engineer's consideration of people, the design of systems involving people, and the manner by which human performance is analyzed requires a fundamental, analytical approach that is essentially different from other engineering disciplines.

The contribution of the Industrial Engineer is in the management decision-making process. The problems existing in this area deal with the optimum utilization of men, materials, equipment, and energy to achieve the purpose of an organization. The organization may be an individual department of a company, a hospital, an entire corporation, or any other group organized to produce a product, perform a service or carry out a function. The managers of the organization need factual information arranged to define alternatives and consequences, to help them recognize and solve existing problems. The Industrial Engineer collects, analyzes, and arranges this information in such a way as to fulfill this management need, as well as searching for better ways to do the job. The Industrial Engineer operates in two major areas, the design of new systems and the maintenance and improvement of existing systems.

To summarize, in his work the Industrial Engineer:

1. Identifies problems, gathers facts and appraises difficulties.
2. Visualizes solutions and designs, develops or improves systems.
3. Searches out requirements for quality, quantity, cost and timing.

[1] "Management" is defined to mean anyone with line responsibility and authority to direct others in any type of activity; everyone from President, General Manager, and Superintendent to Foreman.

4. Makes economic analyses and justifies their results.
5. Specifies, constructs, installs and, sometimes, initially operates these systems.
6. Devises methods of controlling and evaluating the performance of systems.
7. Develops acceptance by and secures cooperation of those who operate such systems.

The Industrial Engineer is distinguished from other engineers in that he:

1. Places increased emphasis on the integration of the human being into the system.
2. Concerns himself with the total problem.
3. Predicts and interprets the economic results.
4. Makes greater utilization of the contributions of the social sciences than do other engineers.

4. INTERPRETATION FOR THE GENERAL PUBLIC (WITH SPECIAL EMPHASIS FOR HIGH SCHOOL STUDENTS)

The Industrial Engineer is concerned with the design of industrial enterprises or other types of organizations existing for a worthwhile purpose, and the planning or blueprinting of the combination of men, equipment and materials necessary to produce most effectively desired goods or services. The Industrial Engineer differs from other engineers in the degree that his fundamental concern is with operations that result from both physical and human forces, and are measured in both physical and economic terms. Therefore, he is educated not only in the engineering methods of analysis and design which stem from mathematics and the physical sciences, but also is concerned with psychology, physiology, sociology, economics, costs, and human relations.

He may be dealing in the automation of the manufacturing process, in the development of methods of handling materials, in the development of procedures to control production, or to measure performance of any type of work. He frequently serves as management's advisor in the solution of special problems.

In doing his job he comes in contact with all functions of an organization and employees at all levels. He must be able to deal, not only with the technical aspects of his problems, but also the human. Philosophically, he is devoted to the ideal of helping the nation to use most effectively its physical facilities and human talents for production of goods and services.

A person considering Industrial Engineering as a career will find it one of the most rewarding in terms of challenge, recognition, and satisfaction. The Industrial Engineer starting on his career receives the excellent financial compensation of other engineers. The modern Industrial Engineer not only utilizes the traditional engineering tools and techniques in performing his role, but also makes effective application of such new developments as electronic computers and modern data processing devices. In addition, the many new developments in management science are best applied by individuals with the type of education and experience possessed by competent Industrial Engineers. Many Industrial Engineers, by virtue of their area of endeavor and the breadth of their experience, have and will continue to progress into top management.

SYSTEMS DESIGN

One of the key phrases in the Industrial Engineering definition is "systems design". This phrase both indicates the relationship of Industrial Engineering to engineering and emphasizes the unique feature of Industrial Engineering. A symposium was devoted to the presentation and analysis of typical case histories to illustrate the design process in Industrial Engineering, the growing attention to systems problems, the relationship of Industrial Engineering to other branches of engineering, the way in which Industrial Engineering must be co-ordinated with other staff activities, and its operation as an internal consulting function (1).

CASE I

Warren Alberts, Director of Industrial Engineering[2] *United Air Lines, presented a case on the Analysis and Design of an Airline Reservation System.*

The operation of an airline, both from a profit and passenger service standpoint, is extremely dependent upon the speed and accuracy with which it handles and controls the space it has for sale.

United Air Lines' management, in 1955, decided on an over-all analysis of the company's reservation function, including the possible design of a system which would take care of its projected needs through 1965. The system at that time employed over 2,000 people, cost approximately $12,000,000 a year to operate, and was handling up to 50,000 transactions a day. This system could be visualized as a large information processing complex covering some 80 stations spread throughout the country.

The Industrial Engineering Department of United Air Lines undertook the direction of this study. A study team was given the assignment to:

1. Analyze the entire system.
2. Isolate the basic problems.
3. Measure the key variables and project the system and its requirements 10 years into the future.

To help the team concentrate on developing requirements, their initial goal was set as the development of a functional specification. This first phase took approximately a year to complete. Basic problems such as time lags, exposure to human error, divided responsibility, and the inability of people within the system to audit their work, were highlighted. Problems susceptible to short range solutions were turned over to operating groups and an interim system, utilizing IBM Ramac computers at Denver connected to transceivers in the largest reservations offices, was installed.

[2] Subsequently Vice President, Industrial Engineering, now Vice President, Assistant to the President, United Air Lines.

The functional specifications which contained volumes and desired service levels in very specific terms soon pointed up the limitations of existing electronic hardware and communications networks.

A second phase, that of system design and translation of the functional specification into a technical one, was undertaken. Stanford Research Institute was called in as a consultant to evaluate existing technology and help specify a realistic system. Concurrent with the development of technical specifications, a complete economic analysis of existing manpower and machine costs, along with the value of meeting specific design requirements, was made.

This system study, which spanned a period of two years, finally resulted in the procurement by United of a highly advanced electronic reservations system which will not only meet its specifications, but also make an important contribution to profit and increased productivity. The study also pointed up the need to consolidate certain functions basic to the system which previously had been spread out among several departments. These organizational changes were made.

The project dramatically highlighted the importance of taking an over-all Industrial Engineering approach to the analysis and design of complex systems which involve both technical and human aspects. An important point in the approach taken is the development of system requirements which manufacturers are asked to meet as opposed to the current practice of trying to adopt and integrate existing hardware to meet business needs. The results, both in satisfying the company's requirements and in improveing productivity, point up the value of allocating Industrial Engineering effort to the research and development of business systems.

CASE II

Richard Forberg, Director, Industrial Engineering Division, Procter and Gamble Company, presented a case study of the Design of a Synthetic Detergent Production and Distribution System.

A system to produce and distribute synthetic detergents was presented as a whole. The major information flows and the product flow were indicated graphically.

The system was divided into sub-systems, each of which was a major project area. The work on the sub-system for production scheduling and inventory control was presented as a typical project. This study team developed a production scheduling procedure which considered all the significant costs and reduced the time lags in decision making. Installation of the improved system involved simulation, parallel runs, and limited scale tests.

Another sub-system discussed briefly was the mechanized material handling of packaged, finished product. Equipment components for such systems have become commercially available. Designing an integrated system to perform over a wide range of expected levels of consumer demand and modifications of product mix required a total system approach. The use of the Monte Carlo method of simulation to test alternative designs was outlined.

A third sub-system involved the processing of customer orders on electronic data processing equipment. Orders were taken on mark-sense cards by salesmen. A system to process all subsequent paper work necessary for shipment, accounts receivable, sales analysis, and product inventories was under design.

The key role of the Industrial Engineering Division in system design on these separate projects and for coordination at the corporate level was emphasized.

CASE III

George Gustat, Director, Industrial Engineering Division, Eastman Kodak Company, presented a case study of the Mechanization of a Finishing Operation.

An industry was pictured that had successfully employed Industrial Engineering for many years. It has used ideas such as measured work, cost control, quality control and scheduling to strongly aid the organization. In an economic climate of rising input costs, Industrial Engineering had contributed to holding the costs to such a level that it was unnecessary to raise sales prices. However, an expanding market demanded an accelerated growth in production. This, coupled with technological complexity, required that planning be shifted from a five year basis to projections of ten and fifteen years. The conventional methods of Industrial Engineering then being employed were no longer adequate.

A team was used to assess the situation aggressively. A large number of new ideas were presented and scheduled to be worked out and installed in the next ten years on a scheduled priority basis. These suggestions ranged from very minor ones to complete revisions of the productive system.

One of these ideas was presented to demonstrate the development of this improvement scheme. In this case, large quantities of product were being inspected in a rigorous manner to get a product with a low defect rate. To attack this potential problem more effectively, it became necesary for the Industrial Engineer to form a part of a specialized team. It was emphasized that an Industrial Engineer concerned only with restricted techniques would have had little success with this problem, requiring as it does technical knowledge from other fields. Since the present operation was profitable, there was a considerable tendency to multiply the existing types of facility to meet the new demands. A complex machine was developed to replace the human inspection and handling previously employed. The evolutionary development, testing, installation, and redesign were continued over an extended period with a follow-up of Industrial Engineering techniques applicable to a man-machine work unit of high value. Now, the new machine produced a systems schedul-

ing problem for the Industrial Engineers that required a more sophisticated solution.

The success of this productive equipment influenced the expansion plans. Here it was noted that each progressive and needed change in the system caused more changes involving more coordination and planning in the over-all system. In summary, the over-all economic influences and pressures caused Industrial Engineering to become oriented toward an expansive, dynamic improvement program. The narrow and admittedly static concepts of thinking previously used were now being directed toward a broader and more progressive view of the system and the larger potentials for use of resources.

CASE IV

L. T. Ohmart,[3] Manager, Industrial Engineering Department, Armstrong Cork Company, presented a case study of Organization for Systems Design.

The modern national trend in Industrial Engineering has continued to emphasize systems engineering. This has resulted from the realization that Industrial Engineering problems cannot be completely divorced and isolated from their environment. For the Industrial Engineer to properly function, it is necessary that he become less specialized and have a good command of the broader Industrial Engineering functions.

To better serve the needs of making and marketing a competitive product an interesting organizational change was reported. Specialization was deemphasized and individuals with broad scope and background were assigned to areas of functional responsibility. These individuals were grouped into a developmental team that had successive responsibilities as a new product was developed and marketed.

A case study was presented showing the accelerated and coordinated stages employed as a floor backing was successfully moved from research to production. The group of broadly oriented personnel composed a small, coordinated team that now employed various specialists as internal consultants. As the product progressively developed on a time scale, each responsible member of the team could draw on specialists to assist him in accomplishing his part of the mission. The team members were generally drawn from production, research, project engineering and Industrial Engineering.

Successful experience in this organization has shown that if systems engineering work is to be effective, responsible staff people must know and respect what effects their actions will have on other parts of the organization. If the Industrial Engineer is to participate in this system, he should develop a perspective that enables him to look at any problem as an integral part of the whole system.

This orientation of thinking had also been demonstrated to be excellent training for handling emergency systems problems.

From these case studies, what conclusions can be drawn concerning some of the major and distinguishing general aspects of Industrial Engineering?

1. The concept of opportunity-oriented solutions to problems.
2. The concept of Industrial Engineering as a continuum for all management levels.
3. The concept of the emerging role of the Industrial Engineer in a dynamic profession of engineering.
4. The concept of Industrial Engineering as a research, developmental and creative staff function.
5. The recognition of the similarities of the Industrial Engineering systems concepts with those of other branches of engineering. A recognition of some of the distinguishing differences, such as the emphasis on the human component, economic orientation, degree of predictability and probabilistic nature of problems.
6. A recognition of the inadequacies of information about communication from the viewpoints of man-to-man, man-to-machine, or machine-to-machine transfers. Systems design is of course critically dependent upon knowledge of this type.
7. A recognition that both the practicing and academic Industrial Engineer is broadening his intellectual scope as he views and practices Industrial Engineering.

TOOLS AND TECHNIQUES FOR SYSTEMS DESIGN, AND THEIR USE

What are the major tools and techniques that the Industrial Engineer uses in designing systems? The symposium group that examined this subject felt that the list was quite extensive (5). This group did not examine the degree of knowledge and skill the Industrial Engineer should have in each of these areas. The levels of knowledge extend from expert or comprehensive to elementary, i.e. enough to recognize a need and to know where to find expert advice. However, there was agreement that the Industrial Engineer serves as the unifying force in bringing together the knowledge and talents of the various scientific and engineering disciplines, and in developing means for integrating them into a cohesive team to assist management.

Since the Industrial Engineer is concerned with the design, improvement and installation of systems involving men, materials, and equipment, he must have fundamental training in mathematics, physics, chemistry, and in the engineering sciences. The treatment of the human component of the system requires knowledge of the behavior, motivation, capabilities, and limitations of people. Knowledge derived from training in the social sciences, as psychology and sociology, is necessary to predict and describe the variations in the performance of men, equipment and processes and the environmental factors affecting them. The Industrial Engineer makes extensive use of probability and mathematical statistics. A wide variety of special tools and techniques are used in the analysis and design of complex integrated systems. Among these are methods of linear and dynamic programming, gaming theory, digital and analog simulation techniques, control theory, computer applications, and many others asso-

[3] Now Consultant, Methods and Time Standards, General Electric Company.

ciated with recent developments, as well as such tools as process charts, methods analysis and others long associated with Industrial Engineering activities.

The evaluation of both systems and components requires familiarity with various branches of economics and with the techniques of modern decision theory. Tools used in setting standards for and in measuring the performance of men, equipment, and systems range from work sampling, micromotion and time study to synthetic time standards. Since he works closely with management, the Industrial Engineer must be familiar with management principles and organization theory. He must have the experience, skills, and knowledge necessary to design, analyze, and evaluate systems used by management for control of cost, production, and quality. Because he deals with people at every level of the organization and because his work directly affects the activities of these people, the Industrial Engineer must have the special skills necessary to convey his ideas and results by verbal, written and visual methods. This problem of efficient communication is becoming more important as our requirement for more frequent change increases.

How does an Industrial Engineer use these tools and techniques when he first contacts the reality of the problem area? In the initial or *survey phase* he utilizes visual observation and preliminary data samples to design subsequent approaches and determine the scope of his analysis. He would include a review of records that are available for an existing activity and a check for similarities to existing activities if the design is new. From these he would begin to develop a conceptual model of the area under investigation and to comprehend directions in which improvements may be made. The whole process of design through which the Industrial Engineer may subsequently go is carried out in a rough conceptual way in this first approach.

Next the Industrial Engineer must usually design a method of *obtaining additional information.* Normally, this will require the selection of suitable units of measure and the design of data collection or the use of experimental statistics to design such procedures.

The third phase is *modeling,* putting measurement into a form representing some important aspects of the situation. Many tools and techniques are useful in this phase: job standards, process charts, flow diagrams, layout models, simulation programs, or a wide variety of mathematical formulations.

What techniques are available for *manipulating the model* that has been constructed? The simplest manipulative activities are those which the Industrial Engineer recognizes in the "why" approach of work simplification, as used with a job description, process flow chart, or plant layout. For other models, appropriate manipulations are chosen: for example, Monte Carlo methods in process simulation. In addition to the manipulative techniques, the Industrial Engineer uses his creative imagination and experience to develop a range of alternative solutions to the problem.

These phases are part of a repetitious, cyclical process which may be repeated several times to evolve a design which meets the final design criteria, and which may also be analyzed by the critical processes or decisions of management.

THE INDUSTRIAL ENGINEERING PROCESS

The combination of activities referred to immediately above can be considered a part of the Industrial Engineering "process" (2). This process can be charted to facilitate its understanding and discussion (Figure 1). The chart is intended to graphically illustrate these activities and to classify them as either operating, engineering, or research. The boxes across the top represent the engineering activities in the Industrial Engineering process. Across the bottom are the "operating" activities which have often characterized the Industrial Engineering Department in a company. As has been noted, the trend is away from such narrow use of the term "Industrial Engineering" by management. Up the left side is illustrated the research activities, the refinement of existing techniques, the development of new techniques and problem solving tools, and the transfer of techniques from other areas of endeavor. The relation to management and the objectives of the organization are also noted. The symposium group endorsed the diagram as depicting the process by which change can be engineered and controlled—i.e., the *Industrial Engineering Process.*

AREAS OF OPPORTUNITY FOR THE FUTURE

The Industrial Engineering concept has been defined and explained. The unique aspect of this branch of engineering, systems design, has been defined and illustrated by case examples. The tools and techniques of the Industrial Engineer and the manner of their use by him have been examined. A key topic remains to be explored: areas of opportunity for the continued application and future growth of the Industrial Engineering approach.

The symposium group that discussed this subject felt it important to set the stage for this discussion by depicting how modern management thinks of an Industrial Engineer (6). In addition to his traditional role in work measurement, cost studies, plant layout, etc., management now looks upon the Industrial Engineer as one concerned with:

1. Analyzing, developing, and implementing an entirely new system consistent with modern decision methods and computer technology.
2. Improving the performance and output of an existing system of men, machines, materials, and information regardless of whether it is in the manufacturing function (where most Industrial Engineering activities have sprung up and are concentrated) or in the budgetary, legal or sales function.
3. Improving the design of existing controlling systems.

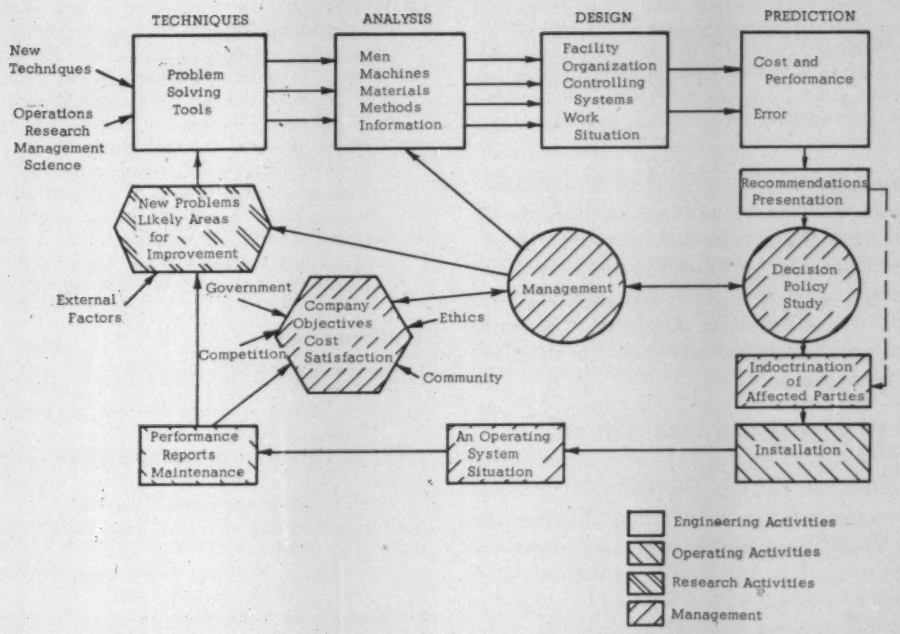

FIGURE 1. The Industrial Engineering Process.

Further, three trends in the pattern of the Industrial Engineer's activities were noted. The first trend is a shift in emphasis from action after the fact to action before the fact on the part of the Industrial Engineer, i.e. a shift from controlling or helping to control what exists to the task of *designing* improvements or innovations. Thus, in addition to the opportunity to develop solutions for a given problem, management is giving the Industrial Engineer opportunity to diagnose the basic problem and to search out new solutions.

The second trend observed is the use of the Industrial Engineer in a more creative role in support of dynamic modern business. In implementing the concepts of science and engineering, management is faced with many problems of an application and acceptance nature. The Industrial Engineer is turning from the routine operation of various controlling systems to the task of speeding the installation of new manufacturing technologies and the timely acceptance of change by those affected. Support of such research and development activities by Industrial Engineering analysis is producing much needed reduction in installation time for new products and processes, as well as new systems of management.

The third trend lies in the increasing development of factual and unbiased solutions based on an increased ability to measure, understand, and manipulate systems. The Industrial Engineer has a significant role in the use of operations research and system analysis for such studies. In addition to such study, the Industrial Engineer is concerned with more than merely being responsible for the development of such solutions. He also lays the foundation for ultimate acceptance at the very outset of his work; he should keep up the promotion and stimulation of interest during his work; and he should complete his work with a presentation which utilizes the skills necessary to secure the full understanding needed for a decision to accept and implement.

The major areas where the Industrial Engineer can directly serve management in key staff-role were identified:

1. Establishment, clarification, and modification of company objectives. The definition of mission and direction of a company as well as its components.

2. Design of an organization or a system of human physical resources used to accomplish these objectives.

3. Recommendations concerning the allocation of the resources that have been organized, whether they be staff, operating, or line. This allocation must not only be initially determined but must be kept continually in balance. Here management is looking for an engineering approach in the determination of where their dollars, their human, or their physical resources can be invested for the greatest return.

4. Design of the basic system by which these resources are utilized. Included here is not only the operational system by which these resources distribute or provide goods and services, but also the staff system which serves the operational system. The same types of operational improvement are possible in functional areas outside of the traditional manufacturing area—for example, sales and research and development control.

5. Design of control systems for these resources. The systems by which the planning, scheduling, or co-ordinating of resources is done represents an important area for company improvement and is a challenging design opportunity.

6. The evaluation of results achieved in the performance toward objectives, i.e., the realization from the investment in human, physical, or money resources as measured by the satisfaction of human and management wants. Such evaluation, though difficult,

provides conclusions which when fed back close the loop described in sections 1 through 5. If the realization obtained is not satisfactory, the Industrial Engineer is asked to re-examine the organization, objectives, allocations, resources, use, control and realization. This full circuit can be generally applied to any type of organized human activity—industry or government, product or service producing.

In these areas management is looking to an Industrial Engineer more and more as an individual who can step back far enough from the day-to-day operations to observe objectively the system by which the company is run rather than as a specialist in a particular area. Further, management looks to an Industrial Engineer to assist in interpreting what he has seen and experienced to the other people in the organization.

THE RELATION OF INDUSTRIAL ENGINEERING AND MANAGEMENT

Much of the material developed in the symposia has centered on the contributions of Industrial Engineering to management. This subject was discussed at the Northwestern Symposium by Dr. Alex Rathe (AIIE National President for 1960-61), where it was pointed out that Industrial Engineering employs engineering thinking, principles and methodology. It also uses the knowledge from other fields, particularly the physical and social sciences and mathematics. The mission of the engineer is "design," that of management is direction of "operations."

Where the Industrial Engineer serves management, he can perform many managerial tasks. However, these can only be in the service and auxiliary phases of management—i.e. in planning, in review, and in management research and development. In the "operations" section of management the engineer, as an engineer, is a stranger. Some engineers have become effective managers in management's main area, that of operations. Before this could occur, these persons had to develop special personal traits and gain experience and knowledge beyond that acquired in engineering. The reverse movement (where managers have become engineers) has only rarely occurred in the past and is less likely to do so in the future.

A dramatic change has taken place in the Industrial Engineering profession. Emphasis is now being placed on action before the fact rather than after. Greater attention is now being given to the creative role in support of dynamic modern business. And most importantly, the Industrial Engineer is now teaming with others to stress the scientific, the economic and the management aspects of an organization.

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APPENDIX NO. 1

SYMPOSIA DATES AND LOCATIONS

1. Cornell University, Ithaca, New York, October 20 and 21, 1955
   Host: Dr. Andrew Schultz, Jr.
2. Purdue University, E. Lafayette, Indiana, November 15 and 16, 1956
   Host: Professor Harold Amrine
3. Georgia Institute of Technology, Atlanta, Georgia, November 7 and 8, 1957
   Co-Hosts: Professor Frank Groseclose, Dr. Robert Lehrer
4. University of Iowa, Iowa City, Iowa, November 10 and 11, 1958
   Host: Professor Wayne Deegan
5. Northwestern University, Evanston, Illinois, November 16 and 17, 1959
   Host: Dr. Robert Lehrer

APPENDIX NO. 2

SYMPOSIA PARTICIPANTS

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Ohio State University

Dr. L. S. Christie
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Western Electric Corporation

Mr. R. Conrad Cooper
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United States Steel Corporation

Dr. H. O. Davidson
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Operations Research Incorporated

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Mr. C. W. Lake
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Dr. R. N. Lehrer
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Northwestern University

Mr. D. G. Malcolm
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Mr. Austin Weston
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Mr. Lee S. Whitson
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Toro Manufacturing Corporation

Special Issue FOR MANAGEMENT

Industrial Engineering is concerned with the design, improvement, and installation of integrated systems of men, materials and equipment; drawing upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design, to specify, predict, and evaluate the results to be obtained from such systems.

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